A P P L I C A T I O N

for

UNITED STATES LETTERS PATENT

on

METHODS OF IDENTIFYING LUNG HOMING MOLECULES USING MEMBRANE DIPEPTIDASE

by

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Sheets of Drawings: 11

Docket No.: P-LJ 4377

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METHODS OF IDENTIFYING LUNG HOMING MOLECULES USING MEMBRANE DIPEPTIDASE

This application is a continuation-in-part of U.S. Application Serial No. 09/042,107, filed March 13, 1998, the entire contents of which is incorporated herein by reference.

This invention was made with government support under grant numbers CA 74338 and CA 30199 awarded by the National Institutes of Health.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates generally to the fields of molecular medicine and drug delivery and, more specifically, to molecules that home to a specific organ or tissue.

BACKGROUND INFORMATION

Although the effect of a particular pathology often is manifest throughout the body of the afflicted person, generally, the underlying pathology may affect only a single organ or tissue. It is rare, however, that a drug or other treatment will target only the diseased organ or tissue. More commonly, treatment results in undesirable side effects due, for example, to generalized toxic effects throughout the patient's body. It would be desirable to selectively target organs or tissues, for example, for treatment of diseases associated with the target organ or tissue.

In particular, targeting of an organ or tissue can be useful for directing the expression of a gene to a certain organ or tissue because incorporation of a foreign gene into nontargeted cells can cause unwanted side effects such as malignant transformation.

Most therapeutic substances are delivered to the target organ or tissue through the circulation. The endothelium, which lines the internal surfaces of blood vessels, is the first cell type encountered by a circulating therapeutic substance in the target organ or tissue. These cells provide a target for selectively directing therapies to an organ or tissue.

Endothelium can have distinct morphologies and biochemical markers in different tissues. The blood vessels of the lymphatic system, for example, express various adhesion proteins that serve to guide lymphocyte homing. For example, endothelial cells present in lymph nodes express a cell surface marker that is a ligand for L-selectin and endothelial cells in Peyer's patch venules express a ligand for the $\alpha_4\beta_7$ integrin. These ligands are involved in specific lymphocyte homing to their respective lymphoid organs. Thus, linking a drug to L-selectin or to the $\alpha_4\beta_7$ integrin may provide a means for targeting the drug to diseased lymph nodes or Peyer's patches, respectively, provided that these molecules do not bind to similar ligands present in a significant number of other organs or tissues.

Although the homing molecules present in the blood vessels of non-lymphoid tissues have not been clearly defined, certain observations of lymphocyte

circulation suggest that organ and tissue specific endothelial markers exist. Similarly, the homing or metastasis of particular types of tumor cells to specific organs or tissues further suggests that organ and tissue specific markers may exist. Thus, a need exists to identify molecules that can bind to such organ or tissue specific markers and, therefore, can home to the organ or tissue. The present invention satisfies this need and provides related advantages as well.

SUMMARY OF THE INVENTION

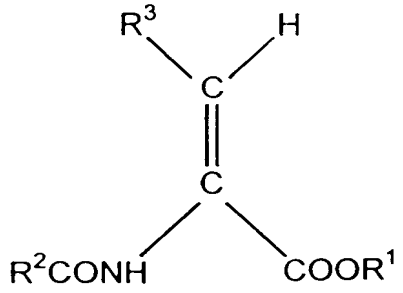
The present invention provides a method of identifying a membrane dipeptidase (MDP)-binding homing molecule, which is a molecule that selectively homes to lung endothelium. The method includes the steps of contacting MDP with one or more molecules; and determining specific binding of a molecule to the MDP, where the presence of specific binding identifies the molecule as a MDP-binding homing molecule that selectively homes to lung endothelium. In a method of the invention, the MDP can be, for example, in its natural state or substantially purified and, if desired, immobilized on a support. The membrane dipeptidase can be any mammalian MDP, for example, human MDP having SEQ ID NO: 448.

Further provided by the invention is a method of selectively directing a moiety to lung endothelium in a subject by administering to the subject a conjugate containing a moiety linked to a MDP-binding homing molecule that selectively homes to lung endothelium, whereby the moiety is selectively directed

to lung endothelium in the subject. Such a method can be useful, for example, for drug targeting to lung. In a method of the invention, the MDP-binding homing molecule is identified by contacting membrane dipeptidase (MDP) with one or more molecules; and determining specific binding of a molecule to the MDP, where the presence of specific binding identifies the molecule as a MDP-binding homing molecule that selectively homes to lung endothelium. A variety of moieties can be selectively directed to lung endothelium according to a method of the invention. A moiety useful in the invention can be, for example, a gene therapy vector or drug.

In one embodiment, the invention provides a method for selectively directing a moiety to lung endothelium where the MDP-binding homing molecule is a peptide including the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids. Such a MDP-binding homing peptide can include, for example, the sequence CGFECVRQCPERC (SEQ ID NO: 1) or CGFELETC (SEQ ID NO: 2).

In another embodiment, the invention provides a method for selectively directing a moiety to lung endothelium where the MDP-binding homing molecule contains the following Structure 1:



where R^2 and R^3 are hydrocarbon radicals in the range respectively of 3-10 and 1-15 carbon atoms; in either one of these R^2 or R^3 hydrocarbon chains 1-6 hydrogens may be replaced by halogens or a nonterminal methylene may be replaced by oxygen or sulfur, including oxidized forms of the latter; additionally, a terminal hydrogen in R^3 can also be replaced by hydroxyl or thiol, which may be acylated or carbamoylated; or the hydrogen can be replaced by amino, which may be derivatized as in an acylamino, ureido, amidino, quanidino, or alkyl or substituted amino group, including quaternary nitrogen grouping; or, there may be replacement by acid groups such as carboxylic, phosphonic or sulfonic acid groups or esters or amides thereof, or cyano; or combinations thereof, such as a terminal amino acid grouping; and R^1 is hydrogen or lower alkyl (C_{1-6}) or dialkylaminoalkyl, or a pharmaceutically acceptable cation. Such an MDP-binding homing molecule for reducing or preventing lung metastasis can be, for example, 7-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid, also known as cilastatin.

An MDP-binding homing molecule can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl with a limitation that the carbon adjacent to the carbonyl cannot be tertiary.

An MDP-binding homing molecule also can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl with a limitation that the carbon adjacent to the carbonyl cannot be tertiary, and in which R^3 is n-alkyl (1-9 carbons) or n-alkyl (1-9 carbons) having a terminal substituent which is a quaternary nitrogen, amine derivative or amino acid derived group. An MDP-binding homing molecule can be, for example, a compound having Structure 1 in which R^2 is 2,2-dimethylcyclopropyl or 2,2-dichlorocyclopropyl and in which R^3 is a hydrocarbon chain of 3 to 7 carbon atoms without a terminal substituent or having a terminal substituent which is trimethylammonium, amidino, guanidino or 2-amino-2-carboethylthio.

Exemplary MDP-binding homing molecules having Structure 1 useful in the invention include the following: Z-2-(2,2-dimethylcyclopropane carboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dichlorocyclo propanecarboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dimethylcyclopropane carboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-ureido-2-octenoic acid; Z-8-(1-2-amino-2-carboxy ethylthio)-2-(2,2-dimethylcyclopropane

carboxamido)-2-octenoic acid; Z-2-(2,2-dimethylcyclopropane carboxamido)-2-octenoic acid (racemic and dextrorotatory forms); Z-2-(2,2-dichloro cyclopropanecarboxamido)-2-octenoic acid; 7-(L-2-amino-2-carboxyethylthio) -2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid; and 6-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-hexenoic acid.

The present invention also provides a method of reducing or preventing lung metastasis in a subject having cancer by administering to the subject a membrane dipeptidase (MDP)-binding homing molecule. In a preferred embodiment, an MDP-binding homing molecule is a lung homing peptide including the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids, such as a peptide including the sequence CGFECVRQCPERC (SEQ ID NO: 1) or CGFELETC (SEQ ID NO: 2).

In another preferred embodiment, an MDP-binding homing molecule is a molecule containing Structure 1, described hereinabove. Such an MDP-binding homing molecule can be, for example, 7-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid, commonly known as cilastatin.

In one embodiment, an MDP-binding homing molecule useful in the invention is an MDP inhibitor. Such an MDP inhibitor can exhibit, for example, a Ki against MDP of 1000 nM or less. In other embodiments,

an MDP inhibitor useful in reducing or preventing lung metastasis exhibits a Ki against MDP of 100 nM or less or a Ki against MDP of 1 nM or less.

The present invention also provides a method of reducing or preventing lung metastasis in a subject having cancer by administering to the subject a MDP negative regulatory agent. A MDP negative regulatory agent useful in the invention can be, for example, a soluble MDP polypeptide or an antibody that selectively reacts with MDP.

Further provided herein are methods of reducing or preventing cell homing to lung endothelium in a subject by administering to the subject a MDP negative regulatory agent. A MDP negative regulatory agent useful for reducing or preventing cell homing to lung endothelium can be, for example, a soluble MDP polypeptide or an antibody that selectively reacts with MDP.

The present invention also provides a method of identifying a molecule that reduces or prevents lung metastasis by contacting membrane dipeptidase (MDP) with one or more molecules; and determining MDP activity in the presence of the molecule as compared to a control value, where diminished MDP activity in the presence of the molecule identifies the molecule as a molecule that reduces or prevents lung metastasis. The membrane dipeptidase can be, for example, substantially purified. MDP activity can be determined, for example, by release of D-Phe from Gly-D-Phe.

In one embodiment, the invention provides a method of identifying a molecule that reduces or prevents lung metastasis by contacting MDP with one or more molecules; determining MDP activity in the presence of the molecule as compared to a control value; administering the molecule to a subject having cancer; and assaying lung metastasis in the subject as compared to a control level of metastasis, where diminished MDP activity in the presence of the molecule identifies the molecule as a molecule that reduces or prevents lung metastasis.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the results of three rounds of *in vivo* panning of a CX_6C (SEQ ID NO: 26) library for identifying molecules that home to lung. Phage recovered from the lung five minutes after injection of 10^{10} transducing units into the tail vein of mice were amplified and reinjected in two consecutive rounds. The number of phage recovered per gram of lung, kidney or brain is indicated for each round, with bars representing standard error of the mean from triplicate platings.

Figures 2A to 2D show the selectivity of phage displaying a lung (Figures 2A and 2B), skin (Figure 2C) or pancreas (Figure 2D) homing peptides. Selected phage expressing peptides that home to lung (Figure 2A, CGFECVRQCPERC, SEQ ID NO: 1, "GFE-1"; Figure 2B, CGFELETC, SEQ ID NO: 2, "GFE-2"); skin (Figure 2C, CVALCREACGEGC, SEQ ID NO: 3) or pancreas (Figure 2D, SWCEPGWCR, SEQ ID NO: 4) were individually

amplified, injected into mice and recovered (Example I). The amount of phage displaying a selected peptide that was recovered per gram of lung, skin or pancreas or control kidney or brain was determined. The amount of unselected (control) phage recovered from lung, skin, pancreas, kidney or brain also was determined. Bars indicate standard error of the mean from triplicate platings.

Figures 3A and 3B show the effect of coadministration of glutathione S-transferase- (GST)-fusion proteins on the homing of phage displaying lung or skin homing peptides.

In Figure 3A, 100 µg or 500 µg of GST-CGFECVRQCPERC (SEQ ID NO: 1, "GFE-1") or 500 µg GST was coinjected into mice with 10^9 transducing units of the individually amplified phage displaying the lung homing sequence CGFECVRQCPERC (SEQ ID NO: 1). The recovery of phage after 5 minutes of circulation from lung and kidney was determined, with bars indicating standard error of the mean from triplicate platings.

In Figure 3B, 10^9 transducing units of individually amplified phage displaying either the lung homing peptides CGFECVRQCPERC (SEQ ID NO: 1, "GFE-1") or CGFELETC (SEQ ID NO: 2, "GFE-2") or the skin homing peptide CVALCREACGEGC (SEQ ID NO: 3) were coinjected into mice with 500 µg of the cognate GST-fusion peptide. Control mice (not shown) were injected with the selected phage and 500 µg of GST. The percentage of inhibition of selected phage homing to lung or skin in the presence of the cognate GST-fusion peptide compared to GST is shown.

Figure 4 shows that a 55 kDa cell surface protein from lung extracts specifically binds to a GFE-1 peptide affinity column. An *in vivo* biotinylated lung extract was fractionated on a CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) peptide column or on a control peptide column (GRGESP; SEQ ID NO: 442), washed, and eluted with GFE-1 peptide. Aliquots (30 µl) from the wash fraction ("-"), GFE-1 peptide elution, and 8M urea elution were resolved by SDS-PAGE under reducing conditions. Molecular weight markers (in kDa) are indicated on the right side of each panel.

Figure 5 shows a time course of the fluorimetric detection of D-phenylalanine (D-Phe) produced by hydrolysis of Gly-D-Phe. Samples from the wash fraction (○) and the CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) peptide eluate (●) from a GFE-1 peptide affinity column were assayed for MDP activity with a Gly-D-Phe substrate. The time-dependent conversion of D-Phe into a fluorescent compound is shown.

Figure 6 shows binding of phage bearing peptide CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) or CGFELETC (SEQ ID NO: 2; GFE-2) to COS-1 cells expressing membrane dipeptidase (MDP).

In Figure 6A, COS-1 cells were transfected with the MDP expression vector or vector alone. Two days after the transfection, cell extracts were prepared and analyzed for MDP activity.

In Figure 6B, COS-1 cells transfected with either the MDP expression vector or control empty vector were subjected to a binding assay in the

presence of equal amounts of either control phage (fd-tet) or phage bearing the skin-homing peptide CVALCREACGEGC (SEQ ID NO: 3; "shp-1"), CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) peptide, or CGFELETC (SEQ ID NO: 2; GFE-2) peptide. In each case, the total number of phage transducing units rescued from these cells is shown. Error bars indicate standard deviation of the mean from triplicate platings.

Figure 7 shows inhibition of MDP activity by the GFE-1 peptide CGFECVRQCPERC (SEQ ID NO: 1). Extracts from MDP-expressing COS-1 cells were assayed for MDP activity in the presence of increasing concentrations of CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) (●) or CARAC control peptide (SEQ ID NO: 443), shown as (○).

Figure 8 shows that GFE-1 (SEQ ID NO: 1) inhibits lung metastasis of human melanoma cells. Lung weight is shown for mice five weeks after injection with 10^5 C8161 human melanoma cells alone ("vehicle"); 10^5 C8161 cells coadministered with 250 µg GFE-1 peptide SEQ ID NO: 1 ("GFE-1 peptide"); or 10^5 C8161 cells coadministered with 250 µg CARAC peptide SEQ ID NO: 443 ("control peptide").

Figure 9 shows an alignment of the predicted amino acid sequences of membrane dipeptidase from five species. The amino acid sequences of the human ("HUM;" SEQ ID NO: 448); pig ("PIG;" SEQ ID NO: 449); rat ("RAT;" SEQ ID NO: 450); and mouse ("MOU;" SEQ ID NO: 451) MDPs are aligned together with the sequence of rabbit MDP ("RAB;" SEQ ID NO: 452). Asterisks indicate *N*-linked glycosylation sites in human MDP. The boxed

residues Glu^{125} and His^{219} are essential for activity (Adachi et al., Biochim. Biophys. Acta 1163:42-48 (1993); Keynan et al., FEBS Letters 349:50-54 (1994)). Underlined residues (-1 to -16) represent the signal peptide. The boxed residues at the C-terminus indicate the hydrophobic signal that is replaced by a glycosyl-phosphatidylinositol (GPI) anchor in the mature protein. The site of GPI anchor addition is indicated by an arrow.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides organ and tissue homing molecules and methods of using these molecules to target a moiety to a selected organ or tissue. The molecules of the invention, which were identified essentially by the method of *in vivo* panning (U.S. Patent No. 5,622,699, issued April 22, 1997, which is incorporated herein by reference), include peptides that home to various normal organs or tissues, including lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut, and to organs bearing tumors, including to lung bearing lung tumors and to pancreas bearing a pancreatic tumor. For example, the invention provides lung homing peptides, including the peptides CGFECVRQCPERC (SEQ ID NO: 1) and CGFELETC (SEQ ID NO: 2), each of which contains a tripeptide GFE motif, and the peptide GIGEVEVC (SEQ ID NO: 8). The invention also provides skin homing peptides such as the peptide CVALCREACGEGC (SEQ ID NO: 3); pancreas homing peptides such as the peptide SWCEPGWCR (SEQ ID NO: 4) and retina homing peptides such as the peptides CSCFRDVCC (SEQ ID NO: 5) and CRDVVSVIC (SEQ ID NO: 6), each of which contains a

tripeptide RDV motif. Examples of peptides that home to prostate, ovary, lymph node, adrenal gland, liver and gut are also provided (see Tables 2 to 11). It should be recognized that motifs common to particular organ homing peptides can be identified by simple inspection of the peptides. For example, inspection of Table 9 reveals that the peptides AGCSVTVCG (SEQ ID NO: 315) and AGCVQSQCY (SEQ ID NO: 370) share an AGC motif; the peptides LECRRWRCD (SEQ ID NO: 328) and LECVANLCT (SEQ ID NO: 337) share an LEC motif; and the peptides SECAYRACS (SEQ ID NO: 319) and SECYTGSCP (SEQ ID NO: 375) share an SEC motif. In addition, several of these peptides were isolated more than one time (see asterisks in Table 9), indicating that such motifs are relevant to the ability of the peptides to selectively home. Peptides comprising the particular motifs disclosed herein, as well as other motifs identifiable by inspection of the disclosed peptides, are considered within the claimed invention, provided that the motif is not an RGD motif.

The homing molecules of the invention are useful for targeting a moiety to a particular organ or tissue. Thus, the invention provides conjugates, comprising an organ homing molecule linked to a moiety. Such moieties can be a therapeutic agent such as a virus; a viral gene therapy vector; a drug; a detectable or imaging agent such as a radionuclide; or a tag such as biotin. As disclosed herein, such organ homing molecules of the invention, particularly conjugates of the invention, can be used to detect or visualize a selected organ or tissue or to diagnose or treat a pathology in a selected organ or tissue. An organ homing molecule of the invention also can be used

to isolate the target molecule that is expressed in the selected organ or tissue and binds the organ homing molecule. For convenience, a molecule of the invention that homes to a selected organ or tissue is referred to as an "organ homing molecule."

As used herein, the term "molecule" is used broadly to mean an organic compound having at least one reactive group that can be varied by substituting one or more different groups. An organic molecule can be a drug; a nucleic acid molecule, including RNA or DNA; a peptide; a variant or modified peptide or a peptide mimetic; a protein or a fragment thereof; an oligosaccharide; a lipid; a glycolipid; or a lipoprotein.

An organic molecule can be a naturally occurring molecule, which can be a product of nature in that the groups comprising the organic molecule and the bonds linking the groups are produced by biological processes. For example, a naturally occurring organic molecule can be an RNA molecule or a fragment thereof, which can be isolated from a cell or expressed from a recombinant nucleic acid molecule. Similarly, a peptide is considered a naturally occurring organic molecule, even if it is produced by chemical synthesis, since the amino acid groups and bonds linking the groups can be produced by normal biological processes and the peptide, itself, can be produced in a cell due, for example, to proteolytic degradation of a protein containing the peptide.

An organic molecule also can be a nonnaturally occurring molecule. Such molecules have

chemical groups or bonds that are not normally produced by biological processes. For example, a nucleic acid sequence containing nonnaturally occurring nucleoside analogs or phosphorothioate bonds that link the nucleotides and protect against degradation by nucleases are examples of nonnaturally occurring molecules. A ribonucleotide containing a 2-methyl group, instead of the normal hydroxyl group, bonded to the 2'-carbon atom of ribose residues, is an example of a non-naturally occurring RNA molecule that is resistant to enzymatic and chemical degradation. Other examples of nonnaturally occurring organic molecules include RNA containing 2'-aminopyrimidines, such RNA being 1000x more stable in human serum and urine as compared to naturally occurring RNA (see Lin et al., Nucl. Acids Res., 22:5229-5234 (1994); and Jellinek et al., Biochemistry, 34:11363-11372 (1995), each of which is incorporated herein by reference).

For convenience, the term "peptide" is used broadly herein to mean peptides, polypeptides, proteins and fragments of proteins. Other molecules useful in the invention include peptoids, peptidomimetics and the like. With respect to the organ or tissue homing peptides of the invention, peptidomimetics, which include chemically modified peptides, peptide-like molecules containing nonnaturally occurring amino acids, peptoids and the like, have the binding activity of an organ homing peptide upon which the peptidomimetic is derived (see, for example, "Burger's Medicinal Chemistry and Drug Discovery" 5th ed., vols. 1 to 3 (ed. M.E. Wolff; Wiley Interscience 1995), which is incorporated herein by reference). Peptidomimetics provide various advantages over a

peptide, including that a peptidomimetic can be stable when administered to a subject, for example, during passage through the digestive tract and, therefore, useful for oral administration.

Methods for identifying a peptidomimetic are well known in the art and include, for example, the screening of databases that contain libraries of potential peptidomimetics. For example, the Cambridge Structural Database contains a collection of greater than 300,000 compounds that have known crystal structures (Allen et al., Acta Crystallogr. Section B, 35:2331 (1979)). This structural depository is continually updated as new crystal structures are determined and can be screened for compounds having suitable shapes, for example, the same shape as an organ or tissue homing molecule, as well as potential geometrical and chemical complementarity to a target molecule bound by an organ or tissue homing peptide. Where no crystal structure of a homing peptide or a target molecule, which binds an organ or tissue homing molecule, is available, a structure can be generated using, for example, the program CONCORD (Rusinko et al., J. Chem. Inf. Comput. Sci. 29:251 (1989)). Another database, the Available Chemicals Directory (Molecular Design Limited, Informations Systems; San Leandro CA), contains about 100,000 compounds that are commercially available and also can be searched to identify potential peptidomimetics of an organ or tissue homing molecule.

The term "nucleic acid molecule" also is used broadly to mean any polymer of two or more nucleotides, which are linked by a covalent bond such as a

phosphodiester bond, a thioester bond, or any of various other bonds known in the art as useful and effective for linking nucleotides. Such nucleic acid molecules can be linear, circular or supercoiled, and can be single stranded or double stranded DNA or RNA or can be a DNA/RNA hybrid.

As used herein, the term "library" means a collection of molecules. A library can contain a few or a large number of different molecules, varying from about two to about 10^{15} molecules or more. The chemical structure of the molecules of a library can be related to each other or be diverse. If desired, the molecules constituting the library can be linked to a common or unique tag, which can facilitate recovery and/or identification of the molecule.

Methods for preparing libraries containing diverse populations of various types of molecules such as peptides, peptoids and peptidomimetics are well known in the art and various libraries are commercially available (see, for example, Ecker and Crooke, Biotechnology 13:351-360 (1995), and Blondelle et al., Trends Anal. Chem. 14:83-92 (1995), and the references cited therein, each of which is incorporated herein by reference; see, also, Goodman and Ro, Peptidomimetics for Drug Design, in "Burger's Medicinal Chemistry and Drug Discovery" Vol. 1 (ed. M.E. Wolff; John Wiley & Sons 1995), pages 803-861, and Gordon et al., J. Med. Chem. 37:1385-1401 (1994), each of which is incorporated herein by reference). Where a molecule is a peptide, protein or fragment thereof, the molecule can be produced *in vitro* directly or can be expressed from a nucleic acid, which can be produced *in vitro*.

Methods of synthetic peptide and nucleic acid chemistry are well known in the art.

A library of peptide molecules also can be produced, for example, by constructing a cDNA expression library from mRNA collected from a cell, tissue, organ or organism of interest. Methods for producing such libraries are well known in the art (see, for example, Sambrook et al., Molecular Cloning: A Laboratory Manual (Cold Spring Harbor Laboratory Press 1989), which is incorporated herein by reference). Preferably, a peptide encoded by the cDNA is expressed on the surface of a cell or a virus containing the cDNA. For example, cDNA can be cloned into a phage vector such as fuse 5 (Example I), wherein, upon expression, the encoded peptide is expressed as a fusion protein on the surface of the phage.

In addition, a library of molecules can be a library of nucleic acid molecules, which can be DNA, RNA or analogs thereof. For example, a cDNA library can be constructed from mRNA collected from a cell, tissue, organ or organism of interest, or by collecting genomic DNA, which can be treated to produce appropriately sized fragments using restriction endonucleases or methods that randomly fragment genomic DNA. A library comprising RNA molecules also can be constructed by collecting RNA from cells or by synthesizing the RNA molecules chemically. Diverse libraries of nucleic acid molecules can be made using solid phase synthesis, which facilitates the production of randomized regions in the molecules. If desired, the randomization can be biased to produce a library of

nucleic acid molecules containing particular percentages of one or more nucleotides at a position in the molecule (U.S. Patent No.: 5,270,163, issued December 14, 1993, which is incorporated herein by reference).

If desired, the nucleic acid molecules can be nucleic acid analogs that are less susceptible to degradation by nucleases. For example, RNA molecules containing 2'-0-methylpurine substitutions on the ribose residues and short phosphorothioate caps at the 3'- and 5'-ends exhibit enhanced resistance to nucleases (Green et al., Chem. Biol., 2:683-695 (1995), which is incorporated herein by reference). Similarly, RNA containing 2'-amino- 2'-deoxypyrimidines or 2'-fluro- 2'-deoxypyrimidines is less susceptible to nuclease activity (Pagratis et al., Nature Biotechnol., 15:68-73 (1997), which is incorporated herein by reference). Furthermore, L-RNA, which is a stereoisomer of naturally occurring D-RNA, is resistant to nuclease activity (Nolte et al., Nature Biotechnol., 14:1116-1119 (1996); Klobmann et al., Nature Biotechnol., 14:1112-1115 (1996); each of which is incorporated herein by reference). Such RNA molecules and methods of producing them are well known and routine (see Eaton and Piekern, Ann. Rev. Biochem., 64:837-863 (1995), which is incorporated herein by reference). DNA molecules containing phosphorothioate linked oligodeoxynucleotides are nuclease resistant (Reed et al., Cancer Res. 50:6565-6570 (1990), which is incorporated herein by reference). Phosphorothioate-3' hydroxypropylamine modification of the phosphodiester bond also reduces the susceptibility of a DNA molecule to nuclease degradation (see Tam et al., Nucl. Acids

Res., 22:977-986 (1994), which is incorporated herein by reference). If desired, the diversity of a DNA library can be enhanced by replacing thymidine with 5-(1-pentynyl)-2'-deoxoridine (Latham et al., Nucl. Acids Res. 22:2817-2822 (1994), which is incorporated herein by reference). Such modified nucleic acid molecules can be useful for the manufacture of a library or for the purpose of being a tag, which is described later below.

As disclosed herein, *in vivo* panning for the purpose of identifying an organ or tissue homing molecule comprises administering a library to a subject, collecting an organ or tissue sample and identifying an organ or tissue homing molecule using various methods well known in the art. Generally, the presence of an organ or tissue homing molecule in a collected organ or tissue is identified based on one or more characteristics common to the molecules present in the library, then the structure of a particular organ or tissue homing molecule can be determined.

A highly sensitive detection method such as mass spectrometry (MS), either alone or in combination with a method such as gas chromatography (GC), can be used to identify homing molecules that are closely related even when present in small amounts in a selected organ or tissue. For example, GC in combination with MS was used to identify two major and four minor lidocaine metabolites following lidocaine injection into rats and the analysis of urine (Coutts et al., J. Chromotogr. 421:267-280 (1987), which is incorporated herein by reference). Similarly, where a library comprises diverse molecules based generally on

the structure of an organic molecule such as a drug, an organ or tissue homing molecule can be identified by determining the presence of a parent peak for the particular molecule.

If desired, the selected organ or tissue can be processed using a method such as HPLC, which can be used to obtain an enriched fraction of molecules having a defined range of molecular weights or polarity or the like from a complex mixture. The enriched fraction of molecules then can be further analyzed for the purposes of identifying organ or tissue homing molecules. For example, HPLC coupled with GC and MS were used to identify seven metabolites of a vitamin D analogue after injection of dihydrotachysterol 3 into a rat and fractionation of an isolated perfused kidney (Porteous et al., Biomed. Environ. Mass Spectrum 16:87-92 (1988), which is incorporated herein by reference). Conditions for HPLC will depend on the structure of the particular molecule and can be optimized by those skilled in the art based on knowledge of the molecule.

The organ homing molecules present in a collected sample of organ or tissue can be recovered from the sample by incubation in a solution having a defined salt concentration and temperature. Selective extraction also can be used to obtain different fractions of organic molecules by sequentially incubating a collected sample in one or more solutions. Such solutions can have a different salt concentration or can effect extraction of an organic homing molecule at a particular temperature. The resulting eluates from the collected sample can be collected separately or can be pooled into one or more fractions and the

organ homing molecules can be detected and identified. Similarly, methods for bulk removal of potentially interfering cellular materials such as DNA, RNA, proteins, lipids or carbohydrates are well known in the art. Such methods can be used to enrich for the particular organ homing molecule from potentially contaminating materials in the collected sample and to increase the sensitivity of detecting the molecule.

Ease of identification of an organ or tissue homing molecule, particularly an untagged molecule, depends upon various factors, including the presence of potentially contaminating background cellular material. For example, where the homing molecule is an untagged peptide, a larger number must home to the organ or tissue in order to identify the specific peptides over the background of cellular protein. In contrast, a much smaller amount of an untagged homing molecule such as a drug is identifiable because such molecules normally are generally absent from or present in very small numbers in the body. In this situation, a highly sensitive method such as MS can be used to identify an organ homing molecule. The skilled artisan will recognize that the method of identifying a molecule will depend, in part, on the structure of the particular molecule.

As disclosed herein, a sufficient number of molecules selectively home to a selected organ or tissue during *in vivo* panning such that the molecules readily can be identified. For example, peptides that were identified two or more times in a particular collected organ (see Table 1). For example, of forty clones sequenced from various selected organs, the gut

homing peptide YSGKWGK (SEQ ID NO: 9) was present in 22% of the clones; the ovary homing peptides EVRSRLS (SEQ ID NO: 10) and RVGLVAR (SEQ ID NO: 11) each was present in 22% of the clones; and the liver homing peptide VKSVCRT (SEQ ID NO: 12) was present in 11% of the clones (see Table 1). Similarly, the lung homing peptides CLAKENVVC (SEQ ID NO: 13) and CGFECVRQCPERC (SEQ ID NO: 1); the skin homing peptide CVALCREACGEGC (SEQ ID NO: 3); and the retina homing peptide CGEFKVGC (SEQ ID NO: 14) each was independently isolated several times during *in vivo* panning of the respective organs, as were other organ homing peptides (see Tables 2 to 11; peptides marked with asterisk). These results demonstrate that a substantial fraction of the identified organ homing molecules have the same structure or, in many cases, share conserved motifs.

Following various *in vivo* panning screens, hundreds of thousands to millions of phage expressing homing peptides were recovered from the respective organ or tissue. Generally, the phage collected from a round of *in vivo* panning were plated on agar, about 250 to 300 clones were selected, grown in 5 ml cultures, then pooled and readministered for a subsequent round of *in vivo* panning ("regular method"). However, in some experiments, 1000 clones were selected, grown in 2 ml cultures, then pooled and administered for a subsequent round of screening; or the entire agar plate was scraped and all of the phage were cultured together and administered for a subsequent round of screening. The peptide inserts of various isolated phage were determined such that, of the millions of phage that homed, only a small number of sequences were identified. These results indicate that specific types

of homing molecules can be present in relatively large proportions in an organ or tissue following *in vivo* homing, thereby increasing the ease with which the molecules can be identified.

Where an organ or tissue homing molecule is a nucleic acid molecule, various assay methods can be used to substantially isolate or identify the molecule. For example, PCR can be particularly useful for identifying the presence of the homing molecule because, in principle, PCR can detect the presence of a single nucleic acid molecule (see, for example, Erlich, PCR Technology: Principles and Applications for DNA Amplification (Stockton Press (1989), which is incorporated herein by reference). PCR also has been used to amplify nucleic acid molecules that bind to a predetermined target *in vitro* and, when the nucleic acids were rendered resistant to nucleases and administered to a subject, they modulated biological processes such as lymphocyte trafficking *in vivo* (see, for example, Hicke et al., J. Clin. Invest. 98:2688-2692 (1996), which is incorporated herein by reference). These findings indicate that nucleic acid molecules are sufficiently stable when administered into the circulation of a subject such that *in vivo* panning can be used to identify nucleic acid molecules that selectively home to an organ or tissue *in vivo*.

The molecules of a library can be tagged, which can facilitate recovery or identification of the organ homing molecules. As used herein, the term "tag" means a physical, chemical or biological moiety such as a plastic or metallic microbead, an oligonucleotide or a bacteriophage, respectively, that is linked to a

molecule of the library. Methods for tagging a molecule are well known in the art (Hermanson, Bioconjugate Techniques, (Academic Press 1996), which is incorporated herein by reference). The link between a molecule and a tag can be a covalent or a non-covalent bond and, if desired, the link can be selectively cleavable from the molecule.

As used herein, the term "shared tag" means a physical, chemical or biological moiety that is common to each molecule in a library. A shared tag can be used to identify the presence of a molecule of the library in a sample or to substantially isolate the molecules from a sample following *in vivo* panning. For example, a library that comprises a population of diverse molecules such as nucleic acids can be linked to a shared tag. If the shared tag is biotin, for example, a nucleic acid homing molecule can be substantially isolated from a selected organ or tissue by binding, for example, to a streptavidin affinity column. The presence of the organ or tissue homing nucleic acid molecule also can be detected by binding with a labeled streptavidin. A peptide such as the hemagglutinin antigen also can be a shared tag, which, when linked to each molecule in a library, allows the use of an antibody specific for the hemagglutinin antigen to substantially isolate homing molecules from a selected organ or tissue. Furthermore, a molecule or a support containing a molecule can be linked to a hapten such as 4-ethoxy-methylene-2-phenyl-2-oxazoline-5-one (phOx), which can be bound by an anti-phOx antibody linked to a magnetic bead as a means to recover the homing molecule. Methods for purifying phOx labeled conjugates are known in the art and the

materials for performing these procedures are commercially available (Invitrogen, La Jolla CA; Promega Corp., Madison WI).

A shared tag also can be a nucleic acid sequence that can be used to identify the presence of molecules of the library in a sample or to substantially isolate molecules of a library from a sample. For example, each of the molecules of a library can be linked to the same selected nucleotide sequence, which constitutes the shared tag. An affinity column containing a nucleotide sequence that is complementary to the shared tag then can be used to isolate the homing molecules from an organ or tissue sample by hybridizing to the shared tag linked to the molecules. A nucleotide sequence complementary to a portion of the shared tag also can be used as a PCR primer such that the presence of molecules containing the shared tag can be identified in a sample by PCR.

A tag also can be a specific or a unique tag. As used herein, the term "specific tag" means a physical, chemical or biological tag that is linked to a molecule in a library and that is unique for the particular molecule. A specific tag is particularly useful if it is readily identifiable. A nucleotide sequence that is unique for a particular molecule of a library is an example of a specific tag, for example, a unique oligonucleotide tag linked to each peptide of a library or peptides (see, for example, Brenner and Lerner, Proc. Natl. Acad. Sci., *USA* 89:5381-5383 (1992), which is incorporated herein by reference). Upon homing to an organ or tissue, the homing peptide can be identified by determining the sequence of the

unique oligonucleotide tag using, for example, PCR (see, for example, Erlich, PCR Technology: Principles and Applications for DNA Amplification (Stockton Press 1989), which is incorporated herein by reference). Similarly, the nucleic acid sequence encoding a peptide displayed on a phage is another example of a specific nucleic acid tag, since sequencing of the nucleic acid identifies the amino acid sequence of the expressed peptide (see Example I). Such unique oligonucleotide sequence tags, when linked to other libraries of molecules, can be used to identify the sequence of the homing molecule linked thereto.

A shared tag and specific tag, in combination, can be particularly useful for isolating and identifying an organ or tissue homing molecule when the homing molecule is present in minute quantities. For example, each molecule of a library can be linked to an oligonucleotide tag which contains two portions; an internal unique nucleotide sequence tag and shared flanking 5' and 3' nucleotide tags that serve as primer binding sites for use in PCR. Each molecule, therefore, contains an oligonucleotide tag having a unique portion to identify the homing molecule and a shared portion to provide PCR primer binding sites. Such a tagged molecule, upon homing to a selected organ or tissue, can be identified by performing PCR using primers that hybridize to the shared flanking 5' and 3' nucleotide tags, then performing DNA sequencing to determine the nucleotide sequence of the internal unique sequence tag. The PCR product can be sequenced directly using one of the PCR primers or the PCR product can be cloned into a vector and the DNA

sequence determined by routine methods well known in the art.

Various other combinations of shared and unique tags can be used. For example, each of the molecules in a library can be linked to a specific nucleotide sequence tag (see, for example, Brenner and Lerner, *supra*, 1992), which also contains a shared 3' nucleotide sequence that can be a primer binding site for use in PCR, and can be further linked to a shared tag such as biotin. Upon homing to an organ or tissue, the particular homing molecule can be substantially isolated from an organ or tissue sample based on the biotin tag. The isolated molecules can then be identified, for example, by PCR based DNA sequencing of the specific tag using the shared 3' nucleotide sequence of the nucleotide tag as a primer binding site.

A tag also can serve as a support. As used herein, the term "support" means a tag having a defined surface to which a molecule can be attached. In general, a tag useful as a support is a shared tag. For example, a support can be a biological tag such as a virus or virus-like particle such as a bacteriophage ("phage"); a bacterium such as *E. coli*; or a eukaryotic cell such as a yeast, insect or mammalian cell; or can be a physical tag such as a liposome or a microbead, which can be composed of a plastic, agarose, gelatin or other biological or artificial material. If desired, a shared tag useful as a support can have linked thereto a specific tag.

As exemplified herein, a peptide suspected of being able to home to a selected normal organ or tissue such as lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut, or to an organ or tissue containing a tumor, for example, a lung containing lung tumors or a pancreas containing a pancreatic tumor, was expressed as the N-terminus of a fusion protein, wherein the C-terminus consisted of a phage coat protein (see Example I). Upon expression of the fusion protein, the C-terminal coat protein linked the fusion protein to the surface of a phage such that the N-terminal peptide was in a position to interact with a target molecule in the organ or tissue. Thus, a molecule having a shared tag was formed by the linking of a peptide to a phage, wherein the phage provided a biological support, the peptide molecule was linked as a fusion protein, the phage-encoded portion of the fusion protein acted as a spacer molecule, and the nucleic acid encoding the peptide provided a specific tag allowing identification of organ and tissue homing peptides.

Where a molecule is linked to a support, the tagged molecule comprises the molecule attached to the surface of the support, such that the part of the molecule suspected of being able to interact with a target molecule in a cell in the subject is positioned so as to be able to participate in the interaction. For example, where the homing molecule is suspected of being a ligand for a growth factor receptor, the binding portion of the molecule attached to a support is positioned so it can interact with the growth factor receptor on a cell in an organ or tissue. If desired, an appropriate spacer can be positioned between the

molecule and the support such that the ability of the potential organ or tissue homing molecule to interact with the target molecule is not hindered. A spacer molecule also can contain a reactive group, which provides a convenient and efficient means of linking a molecule to a support and, if desired, can contain a tag, which can facilitate recovery or identification of the molecule (see Hermanson, *supra*, 1996).

In general, a support should have a diameter less than about 10 µm to about 50 µm in its shortest dimension, such that the support can pass relatively unhindered through the capillary beds present in the subject so as to not occlude circulation. In addition, a support can be biologically inert, so that it does not perturb the normal expression of cell surface molecules or normal physiology of the subject. In addition, a support can be excretable or biodegradable, particularly where the subject used for *in vivo* panning is not sacrificed to collect a sample of a selected organ or tissue.

As used herein, the term "*in vivo* panning," when used in reference to the identification of an organ or tissue homing molecule, means a method of screening a library by administering the library to a subject and identifying a molecule that selectively homes to an organ or tissue in the subject (U.S. Patent No. 5,622,699, *supra*, 1997). The term "administering to a subject", when used in referring to a library of molecules or a portion of such a library, is used in its broadest sense to mean that the library is delivered to a selected organ or tissue in the subject, which, generally, is a vertebrate, particularly a

mammal such as a human. Libraries of molecules can be administered by any route or means of administration, such as intravenously, intramuscularly, orally, optically, ocularly, intraperitoneally, nasally, vaginally, rectally, into the uterus, into a chamber of the eye, into the central or peripheral nervous system, by inhalation, by topical administration, or by injection into any normal organ or tissue or into a pathological region such as a tumor or an organ or tissue involved in a pathology, particularly into the circulatory system of the organ or tissue.

A library can be administered to a subject, for example, by injecting the library into the circulation of the subject such that the molecules pass through the selected organ or tissue; after an appropriate period of time, circulation is terminated, for example, by perfusion through the heart or by removing a sample of the organ or tissue (Example I; U.S. Patent No. 5,622,699, *supra*, 1997; see, also, Pasqualini and Ruoslahti, Nature 380:364-366 (1996), which is incorporated herein by reference). Alternatively, a cannula can be inserted into a blood vessel in the subject, such that the library is administered by perfusion for an appropriate period of time, after which the library can be removed from the circulation through the cannula or the subject can be sacrificed or anesthetized to collect an organ or tissue sample. A library also can be shunted through one or a few organs or tissues including a selected organ or tissue, by cannulation of the appropriate blood vessels in the subject. It is recognized that a library also can be administered to an isolated perfused organ or tissue. Such panning in an isolated

perfused organ or tissue can be useful to identify molecules that bind to the organ or tissue.

The use of *in vivo* panning to identify organ or tissue homing molecules is exemplified herein by screening a phage peptide display library in mice and identifying peptides that selectively homed to lung, pancreas, skin and others, and in rats, for peptides that homed to retina (Examples I and II). However, phage libraries that display other protein molecules, including, for example, an antibody or an antigen binding fragment of an antibody such an Fv, Fd or Fab fragment; a hormone receptor such as a growth factor receptor; or a cell adhesion receptor such as an integrin or a selectin also can be used to practice the invention. Variants of such molecules can be constructed using well known methods such as random, site directed or codon based mutagenesis (see Huse, U.S. Patent No. 5,264,563, issued November 23, 1993, which is incorporated herein by reference) and, if desired, peptides can be chemically modified, for example, by introducing a disulfide bridge, following expression of the phage but prior to administration to the subject. Thus, many different types of phage display libraries can be screened by *in vivo* panning.

Phage display technology provides a means for expressing a diverse population of random or selectively randomized peptides. Various methods of phage display and methods for producing diverse populations of peptides are well known in the art. For example, Ladner et al. (U.S. Patent No. 5,223,409, issued June 29, 1993, which is incorporated herein by reference) describe methods for preparing diverse

populations of binding domains on the surface of a phage. In particular, Ladner et al. describe phage vectors useful for producing a phage display library, as well as methods for selecting potential binding domains and producing randomly or selectively mutated binding domains.

Similarly, Smith and Scott (Meth. Enzymol. 217:228-257 (1993); see, also, Scott and Smith, Science 249: 386-390 (1990), each of which is incorporated herein by reference) describe methods of producing phage peptide display libraries, including vectors and methods of diversifying the population of peptides that are expressed (see, also, Huse, WO 91/07141 and WO 91/07149, each of which is incorporated herein by reference; see, also, Example I). Phage display technology can be particularly powerful when used, for example, with a codon based mutagenesis method, which can be used to produce random peptides or randomly or desirably biased peptides (Huse, U.S. Patent No. 5,264,563, *supra*, 1993). These or other well known methods can be used to produce a phage display library, which can be subjected to the *in vivo* panning method of the invention in order to identify a peptide that homes to a selected organ or tissue.

In addition to screening a phage display library, *in vivo* panning can be used to screen various other types of libraries. For example, nucleic acid molecules that bind to a cell surface receptor have been described (see O'Connell et al., Proc. Natl. Acad. Sci., *USA* 93:5883-5887 (1996); Tuerk and Gold, Science 249:505-510 (1990); Gold et al., *supra* (1995), each of which is incorporated herein by reference). These

in vitro results indicate that a library of nucleic acid molecules also can be examined by *in vivo* panning to identify nucleic acid molecules that home to a selected organ or tissue. Additional libraries suitable for screening include, for example, oligosaccharide libraries (York et al., Carb. Res. 285:99-128, (1996); Liang et al., Science 274:1520-1522, (1996); and Ding et al., Adv. Expt. Med. Biol. 376:261-269, (1995), each of which is incorporated by reference); lipoprotein libraries (de Kruif et al., FEBS Lett. 399:232-236, (1996), which is incorporated herein by reference); glycoprotein or glycolipid libraries (Karaoglu et al., J. Cell Biol. 130:567-577 (1995), which is incorporated herein by reference); or chemical libraries containing, for example, drugs or other pharmaceutical agents (Gordon et al., J. Med. Chem. 37:1385-1401 (1994); Ecker and Crook, Bio/Technology 13:351-360 (1995); each of which is incorporated by reference). Such libraries, if desired, can be tagged, which can facilitate recovery of the molecule from an organ or tissue or its identification as previously described.

In vivo panning provides a method for directly identifying molecules that can selectively home to an organ or tissue. As used herein, the term "home" or "selectively home" means that a particular molecule binds relatively specifically to a target molecule present in the organ or tissue, particularly in the vasculature present in the organ or tissue, following administration to a subject. In general, selective homing is characterized, in part, by detecting at least a two-fold (2x) greater selective

binding of the molecule to an organ or tissue as compared to a control organ or tissue.

Selective homing of a molecule to a selected organ or tissue can be due to selective recognition by the molecule of a particular cell target molecule such as a cell surface protein present on a cell in the organ or tissue. Selectivity of homing is dependent on the particular target molecule being expressed on only one or a few different cell types, such that the molecule homes to only one or a few organs or tissues. In this regard, most different cell types, particularly cell types that are unique to an organ or tissue, can express unique target molecules. Thus, in organs such as liver, spleen or lymph node, where blood circulates through sinusoids formed by the cells specific for the organ, *in vivo* panning can be useful for identifying molecules that home to the particular organ or tissue.

It should be recognized that, in some instances, a molecule can localize nonspecifically to an organ or tissue. For example, *in vivo* panning of a phage display library can result in high background in organs such as liver and spleen, which contain a marked component of the reticuloendothelial system (RES). Thus, nonspecific binding of molecules due to uptake by the RES of such an organ or tissue can make identifying an organ or tissue homing molecule more difficult. However, as disclosed herein, potential nonspecific binding can be circumvented, for example, by perfusion through the heart prior to collecting the selected organ or tissue (Example I).

In addition, selective homing readily can be distinguished from nonspecific binding by detecting differences in the abilities of different individual phage to home to an organ or tissue. For example, selective homing can be identified by combining a putative homing molecule such as a peptide expressed on a phage with an excess of non-infective phage or with about a five-fold excess of phage expressing unselected peptides, injecting the mixture into a subject and collecting a sample of the organ or tissue. In the latter case, for example, provided the portion of injected phage in which an organ or tissue homing peptide is sufficiently low so as to be nonsaturating for the target molecule, a determination that greater than about 20% of the phage in the organ or tissue contain the putative homing molecule is demonstrative evidence that the peptide expressed by the phage is a selective organ or tissue homing molecule. In addition, nonspecific localization can be distinguished from selective homing by performing competition experiments using, for example, phage expressing a putative organ or tissue homing peptide in combination with an excess amount of the "free" peptide (see Example II).

Various methods can be used to prevent nonspecific localization of a molecule to organs or tissues, such as those containing a component of the RES. For example, as disclosed herein, perfusion of a solution through the heart shortly after initiating phage circulation decreased the background binding and allowed identification of peptides that selectively home to lung and liver, both of which contain a component of the RES (see Example II). Furthermore,

coadministration of nonreplicating control phage with a phage display library reduced nonspecific phage trapping in organs such as liver and spleen, which also contain a component of the RES. This approach allowed identification of molecules that selectively home to liver (Example II). Thus, a library of molecules attached to a support can be coadministered with an excess of the support to a subject to inhibit nonspecific binding in an organ or tissue.

Nonspecific uptake by a component of the RES also can be prevented by administering a blocking agent that inhibits uptake by the RES. For example, polystyrene latex particles or dextran sulfate can be administered to the subject prior to the administration of the library (see Kalin et al., Nucl. Med. Biol. 20:171-174 (1993); Illum et al., J. Pharm. Sci. 75:16-22 (1986); Takeya et al., J. Gen. Microbiol. 100:373-379 (1977), each of which is incorporated herein by reference). Such pre-administration of dextran sulfate 500 or polystyrene microspheres has been used to block nonspecific uptake of a test substance by Kupffer cells, which are the RES component of the liver (Illum et al., *supra*, 1986). Similarly, nonspecific uptake of agents by the RES has been blocked using carbon particles or silica (Takeya et al., *supra*, 1977) or a gelatine colloid (Kalin et al., *supra*, 1993). Thus, many methods useful for inhibiting nonspecific uptake by the RES are known in the art and routinely used.

Methods of decreasing nonspecific phage trapping include using phage that display a low background binding to a particular organ or tissue.

For example, Merrill et al. (Proc. Natl. Acad. Sci., *USA* 93:3188-3192 (1996), which is incorporated herein by reference) selected lambda-type phage that are not taken up by the RES and, as a result, remain in the circulation for a prolonged period of time. A comparable filamentous phage variant, for example, can be selected using similar methods.

Selective homing can be demonstrated by determining if a homing molecule for a selected organ or tissue is relatively specific. For example, the amount of homing molecule in a selected organ or tissue can be compared to a control or different organ or tissue. Selective homing also can be demonstrated by showing that molecules that home to an organ or tissue, as identified by one round of *in vivo* panning, are enriched for in a subsequent round of *in vivo* panning. For example, phage expressing the peptides CGFECVRQCPERC (SEQ ID NO: 1) and CGFELETC (SEQ ID NO: 2) were enriched for in the second and third rounds of *in vivo* panning from lung and exhibited a 35-fold and 9-fold enrichment, respectively, as compared to unselected phage (see Example II.B). Furthermore, no selective homing to kidney or brain was detected.

As used herein, the term "selected organ or tissue" is used in its broadest sense to mean a normal organ or tissue or an organ or tissue having a pathology, for example, lung containing lung tumors, to which a molecule can selectively home. Thus, the term "organ or tissue" is used broadly to mean any tissue or organ including a normal or pathological cell type such as a cancer cell, in which case the selected organ or tissue can be a primary tumor or a metastatic lesion.

In general, a selected organ or tissue contains a cell, which can be a cell of the vasculature, that expresses a particular target molecule such as a cell surface protein to which a homing molecule can bind. By performing at least two rounds of *in vivo* panning, the selectivity of homing of the molecule for the selected organ or tissue can be determined. As discussed below, however, in some cases a homing molecule can home to more than one selected organ or tissue, in which case the molecule is considered to be able to selectively home to a family of selected organs or tissues. Generally, however, molecules that home to more than one or a few different organs or tissue are not particularly useful since an advantage of the homing molecules of the invention is that they allow targeting of a particular organ or tissue.

The term "control organ or tissue" is used to mean an organ or tissue other than the selected organ or tissue. A control organ or tissue is characterized by the inability of the organ or tissue homing molecule to home to the control organ or tissue and, therefore, is useful for identifying selective binding of a molecule to a selected organ or tissue (Example II). Where an organ or tissue homing molecule is identified based on its ability to home to a pathologic lesion in an organ or tissue, the control organ or tissue can be a corresponding portion of the selected organ or tissue that does not exhibit the pathologic lesion.

A control organ or tissue can be collected, for example, to identify nonspecific binding of the molecule or to determine the selectivity of homing of

the molecule. In addition, nonspecific binding can be identified by administering, for example, a control molecule, which is known not to home to an organ or tissue but is chemically similar to a putative homing molecule. Alternatively, where the administered molecules are linked to a support, administration of the support, alone, can be used to identify nonspecific binding. For example, a phage that does not contain a peptide fusion protein can be administered to a subject and the selected organ or tissue can be examined to determine the level of nonspecific binding of the phage support.

The steps of administering the library to the subject, collecting a selected organ or tissue and identifying the molecules that home to the organ or tissue, comprise a single round of *in vivo* panning. Although not required, one or more additional rounds of *in vivo* panning generally are performed. Where an additional round of *in vivo* panning is performed, the molecules recovered from the selected organ or tissue in the previous round are administered to a subject, which can be the same subject used in the previous round, where only a part of the organ or tissue was collected.

By performing a second round of *in vivo* panning, the relative binding selectivity of the molecules recovered from the first round can be determined by administering the identified molecules to a subject, collecting the selected organ or tissue, and determining whether more phage displaying a particular molecule are recovered from the organ or tissue following the second round of screening as compared to

those recovered following the first round. Although not required, a control organ or tissue also can be collected and the molecules recovered from the selected organ or tissue can be compared with those recovered from the control organ or tissue. Ideally, few if any molecules are recovered from a control organ or tissue following a second or subsequent round of *in vivo* panning. Generally, however, a proportion of the molecules also will be present in a control organ or tissue. In this case, the ratio of molecules in the selected organ or tissue as compared to the control organ or tissue (selected:control) can be determined. Additional rounds of *in vivo* panning can be used to determine whether a particular molecule homes only to the selected organ or tissue or can recognize a target expressed in one or more other organs or tissues that is identical or is sufficiently similar to the target in the originally selected organ or tissue.

In general, a library of molecules, which contains a diverse population of random or selectively randomized molecules of interest, is prepared, then administered to a subject. Some time after administration, the selected organ or tissue is collected and the molecules present in the selected organ or tissue are identified (see Example I). If desired, one or more control organs or tissues or a part of a control organ or tissue are sampled as well. For example, mice injected with a phage peptide display library, after about 1 to 5 minutes, were anesthetized, then snap frozen or perfused through the heart to terminate circulation of the phage. Lung, pancreas or other organs or tissues and one or more control organs were collected and the phage present in the selected

and control organs were collected. The peptides that selectively homed to the respective organs or tissues were identified (Example II and Tables 1 to 11).

As exemplified herein, experimental animals were sacrificed to collect the selected or control organ or tissue. It should be recognized, however, that only a part of an organ or tissue need be collected to recover a molecule that homes to that organ or tissue. Similarly, only part of an organ or tissue need be collected as a control. Thus, for example, following administration of a library of molecules to a subject, a part of the selected organ or tissue can be collected by biopsy, the homing molecules can be collected and, if desired, amplified and readministered to the same subject for a second round of *in vivo* panning. Where the molecule that is to be administered a second time to the same subject is tagged or linked, for example, to a support, the tag or support should be biologically inert and biodegradable or excretable, so as not to interfere with subsequent rounds of screening.

In vitro screening of phage libraries previously was used to identify peptides that bind to antibodies or to cell surface receptors (Smith and Scott, *supra*, 1993). For example, *in vitro* screening of phage peptide display libraries identified novel peptides that specifically bound to integrin adhesion receptors (Koivunen et al., J. Cell Biol. 124:373-380 (1994a), which is incorporated herein by reference) and to the human urokinase receptor (Goodson et al., Proc. Natl. Acad. Sci., *USA* 91:7129-7133 (1994), which is incorporated herein by reference). Similarly, *in vitro*

screening of nucleic acid molecules identified molecules that specifically bind to antibodies, cell surface receptors or organic molecules (Gold et al., *supra*, 1993, 1995, 1997). For example, RNA molecules that specifically bind to HIV-1 reverse transcriptase were identified using purified HIV-1 reverse transcriptase as the target molecule (Green et al., J. Mol. Biol., 247:60-68 (1995), which is incorporated herein by reference). These *in vitro* methods were performed using defined, well-characterized target molecules in an artificial system. However, such *in vitro* studies provide no insight as to whether a molecule that binds *in vitro* also can bind to the target *in vivo*. For example, endothelial cells grown in culture tend to lose their tissue-specific differences (Pauli and Lee, Lab. Invest. 58:379-387 (1988), which is incorporated herein by reference). Thus, a molecule that binds to a target on a cell *in vitro* may not bind *in vivo* because the target may not be present on the cell. Furthermore, such *in vitro* methods are limited in that they require prior knowledge of the target molecule and yield little if any information regarding *in vivo* utility. For example, Goodson et al. (*supra*, 1994) utilized cultured cells to express a recombinant urokinase receptor to obtain binding peptides. However, the urokinase receptor is expressed in cells of many different organs and tissues and, therefore, a molecule that binds to it can interact with many organs or tissues and would not be considered an organ or tissue homing molecule within the present invention.

In contrast to *in vitro* panning methods, *in vivo* panning requires no prior knowledge or the

availability of a known target molecule to identify a molecule that binds to a target molecule that is expressed *in vivo*. Also, since "nontargeted" organs or tissues are present during the screening, the probability of isolating organ or tissue homing molecules that lack selectivity of homing is greatly reduced. Furthermore, in obtaining organ or tissue homing molecules by *in vivo* panning, any molecules that may be particularly susceptible to degradation in the circulation *in vivo* due, for example, to a metabolic activity, will be selected against and will not be recovered. Thus, *in vivo* panning provides significant advantages over previous methods by identifying molecules that selectively home *in vivo* and, if desired, the target molecule present on a selected organ or tissue.

The identification of the organ homing molecules that selectively home to various normal tissues and to pathologic lesions in a particular organ or tissue, as exemplified herein, indicates that particular endothelial cell target molecules expressed the selected organ or tissue reflects the physiologic or pathologic state of the organ or tissue. Such organ homing molecules that selectively home to an organ or tissue based on a particular physiologic or pathologic condition occurring in the organ or tissue can be identified using the *in vivo* panning method and the selectivity of the homing molecules for the pathologic or physiologic condition of the organ or tissue can be confirmed by immunohistological analysis (Example III). For example, molecules that home to pancreas afflicted with pancreatitis can be identified by *in vivo* panning of a subject having pancreatitis and selectively of the

homing molecule can be confirmed by using immunohistochemistry to compare homing of the molecule in normal pancreas with homing in a pancreas afflicted with pancreatitis.

Homing molecules selective for a normal organ or tissue or an organ or tissue exhibiting a pathological state can be useful for detecting the presence or absence of the pathology. For example, following administration of a prostate homing molecule conjugated to an imaging moiety to a subject, the prostate can be visualized. If the image is abnormal, for example, if the size of the prostate is other than that expected for a size and age matched subject, the imaging result can indicate an abnormal physiologic condition or pathologic condition afflicting the prostate. For example, a conjugate comprising an imaging agent and a prostate homing molecule that homes to normal, but not to abnormal prostate, can be administered to a subject. The identification, for example, of a region of the prostate that does not bind the homing molecule can indicate the occurrence of abnormal blood flow in the prostate and can be diagnostic of a pathologic condition such as the presence of a prostate tumor. A conjugate comprising a molecule that homes to prostate tumor tissue, but not to normal prostate, can be used to image a prostate tumor directly.

A homing molecule selective for an organ or tissue can be used to deliver a therapeutic agent to the organ or tissue. Such selective targeting of the agent can increase the effective amount of the agent delivered to the target organ or tissue, while reducing

the likelihood the agent will have an adverse effect on other organs or tissues. For example, a lung homing molecule can be used to deliver, to the lung of a cystic fibrosis patient, a gene encoding the cystic fibrosis transmembrane receptor (CFTR), which is defective in cystic fibrosis. Thus, the organ homing molecules of the invention are particularly useful for *in vivo* gene therapy, since they provide a means to direct a gene to a desired target organ, thereby increasing the likelihood that the target cells will receive the gene and decreasing the likelihood that normal, nontarget, cells will be adversely affected. A lung homing molecule also can be used to direct a therapeutic agent to the lung, thus sparing nontarget organs or tissues from the toxic effects of the agent. For example, in alveolar bacterial pneumonia, a lung homing molecule can be useful for directing an antibiotic to the afflicted region of the lung, thus increasing the effective amount of the drug at the desired site.

Due to the conserved nature of cellular receptors and of ligands that bind a particular receptor, the skilled artisan would recognize that an organ or tissue homing molecule identified using *in vivo* panning in a mouse or rat also can bind to the corresponding target molecule in the selected organ or tissue of a human or other mammalian species. Such a homing molecule identified using an experimental animal readily can be examined for the ability to bind to the corresponding organ or tissue in a human subject by demonstrating, for example, that the molecule also can bind selectively *in vitro* to a sample of the selected organ or tissue obtained from a human subject.

Alternatively, primary cells or established cell lines derived from a human organ or tissue can be used to test for the *in vitro* binding of the homing molecule. Similarly, primary cells or established cell lines that reflect a particular human organ or tissue pathology can be used to test the binding of homing molecules selective for the pathology. Animal models such as primate models of human pathologies are known and also can be used to test for the homing of the molecules using *in vivo* panning. Thus, routine methods can be used to confirm that an organ or tissue homing molecule identified using *in vivo* panning in an experimental animal also can bind an organ or tissue-specific target molecule in a human subject. Furthermore, *in vitro* contacting of a homing molecule with a sample suspected of containing a selected organ, tissue or pathology can identify the presence of the selected organ, tissue or pathology in the sample. Having identified the target molecule by *in vivo* panning, the artisan would know that it is the true target for an organ homing molecule and, therefore, would know that the target molecule could be used *in vitro* to identify additional organ homing molecules that likely would be specific for the target molecule *in vivo*. Such potential organ homing molecules then could be examined by *in vivo* panning to confirm organ homing ability.

In vivo panning was used to identify peptides expressed by phage that selectively homed to lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut, and to lung containing lung tumors or pancreas containing a pancreatic tumor (Examples II and IV; see, also, Tables 2 to 11). Due to the large size of the phage (300 nm) and the short

time the phage were allowed to circulate, it is unlikely that a substantial number of phage would have exited the circulatory system. Indeed, immunohistochemical studies of various organ and tissue homing molecules demonstrated that the molecules primarily home to and bind endothelial cell surface markers of the vasculature. Thus, the invention provides molecules such as peptides that selectively home to the vasculature of a selected organ or tissue.

Phage peptide display libraries were constructed essentially as described by Smith and Scott (*supra*, 1993; see, also, Koivunen et al., Biotechnology 13:265-270 (1995); Koivunen et al., Meth. Enzymol. 245:346-369 (1994b), each of which is incorporated herein by reference). In some libraries, at least one codon encoding cysteine also was included in each oligonucleotide so that cyclic peptides could be formed through disulfide linkages (Example I). Upon performing *in vivo* panning, peptides that selectively home to lung, pancreas, skin, retina, prostate, ovary, lymph node, adrenal gland, liver or gut or to lung containing lung tumors or to pancreas containing a pancreatic tumor were obtained. Thus, the invention provides various organ homing molecules that selectively home to particular organs or tissue.

Remarkably, some organ homing peptides independently were recovered up to four or more times during a round of the *in vivo* panning procedure (see, for example, Table 1). In addition, various peptides that homed to particular organs or tissues shared conserved amino acid sequence motifs. For example, some lung homing peptides shared a GFE motif; some

TABLE 1

SUMMARY OF IN VIVO TARGETING OF VARIOUS ORGANS

ORGAN/MOTIF (SEQ ID NO:)	% OF MOTIF AMONG ALL CLONES	LUNG/BRAIN RATIO
GUT		
YSGKWGK (9)	22	30
GISALVLS (19)	11	nd
SRRQPLS (153)	11	2
MSPQLAT (159)	11	nd
MRRDEQR (172)		
QVRRVPE (155)		
VRRGSPQ (164)		
GGRGSWE (167)		
FRVRGSP (169)		
RVRGPER (165)		
LIVER		
VKSVCRT (12)	11	nd
WRQNMPL (418)	6	nd
SRRFVGG (406)	6	nd
ALERRSL (408)		
ARRGWTL (405)		
PROSTATE		
SMSIARL (21)	6	34
VSFLEYR (22)	6	17
RGRWLAL (279)	6	nd
ADRENAL GLAND		
LMLPRAD (27)	11	50
LPRYLLS (28)		
R(Y/F)LLAGG (404)		
RYPLAGG (389)		

ORGAN/MOTIF (SEQ ID NO:)	% OF MOTIF AMONG ALL CLONES	LUNG/BRAIN RATIO
OVARY		
EVRSRLS (10)	22	3
FFAAVRS (295)		
VRARLMS (301)		
RVGLVAR (11)	22	5
RVRLVNL (294)		
PANCREAS		
SWCEPGWCR (4)		20
SKIN	9	
CVALCREACGEGC (3)	6	7
CSSGCSKNCLEMC (181)		2
LUNG		
CTLRDRNC (15)	10	8
CGKRYRNC (20)	5	5
CLRPYLNC (45)	10	6
CGFELETC (2)	5	9
CIGEVEVC (16)	5	6
CKWSRLHSC (65)	11	3
CWRGDRKIC (56)	8	2
CERVVGSSC (59)	9	4
CLAKENVVC (13)	13	2
CTVNEAYKTRMC (75)	22	3
CRLRSYGTLSLC (76)	5	0.4
CRPWHNQAHTEC (82)	14	5
CGFECVRQCPERC (1)	40	60

retina homing peptides shared a RDV motif; and some adrenal gland homing peptides shared a LPR motif (see Tables 2, 6 and 11, respectively). Since it is known, for example, that the tripeptide RGD motif is sufficient for integrin binding (Ruoslahti, Ann. Rev. Cell Devel. Biol. 12:697 (1996); Koivunen et al., *supra*, 1995; WO 95/14714), the results disclosed herein indicate that many ligand/receptor interactions can derive their specificity from recognition motifs as small as tripeptides.

None of the sequences of the disclosed organ homing peptides exhibited significant similarity with known ligands for endothelial cell receptors. While many of the organ homing peptides may be contained within larger peptides or proteins, it is not known whether they are able to impart a homing function onto the larger molecule. Based on the previous finding that RGD mediates integrin binding when present within larger peptides and proteins, one skilled in the art would recognize, however, that such homing peptides and motifs could impart a homing function when located within a larger peptide or protein. However, such naturally occurring endogenous peptides and proteins are not considered to be organ or tissue homing molecules within the invention.

The organ or tissue homing peptide molecules exemplified herein range in size from about 7 to 13 amino acids in length. However, based, for example, on the ability of the RGD integrin binding motif to mediate integrin binding by itself or when present in a large protein, it will be recognized that the organ homing molecules of the invention also can be expected

to maintain their homing capability in the context of a significantly longer polypeptide sequence. Thus, an organ homing peptide of the invention can be at least three amino acids, generally at least six amino acids or seven amino acids or more, and can be significantly larger, for example, about 20 to 50 amino acids or 100 amino acids or more.

The invention provides lung homing peptides such as CGFECVRQCPERC (SEQ ID NO: 1) and CGFELETC (SEQ ID NO: 2), which share a GFE motif; CTLRDRNC (SEQ ID NO: 15); and CIGEVEVC (SEQ ID NO: 16; see Table 1), which contains an EVE motif that is similar to the ELE motif present in CGFELETC (SEQ ID NO: 2). The exemplified lung homing peptides were identified by injection of a $CX_3CX_3CX_3C$, (SEQ ID NO: 25), CX_7C (SEQ ID NO: 24) or CX_6C (SEQ ID NO: 26) cyclic library into mice (Example II). The lung homing peptides CGFECVRQCPERC (SEQ ID NO: 1) and CGFELETC (SEQ ID NO: 2) exhibited a 60-fold and 9-fold enrichment, respectively, as compared to unselected phage, with few phage detected in kidney or brain (Example II; see, also, Figures 1 and 2 and Table 1). In addition, the lung homing peptides CTLRDRNC (SEQ ID NO: 15) and CIGEVEVC (SEQ ID NO: 16) exhibited a 8-fold and 6-fold enrichment, respectively, over unselected phage (Table 1). Coinjection of a glutathione-S-transferase-(GST-)CGFECVRQCPERC (SEQ ID NO: 1) fusion peptide with phage expressing the cognate CGFECVRQCPERC (SEQ ID NO: 1) peptide inhibited homing by 70%, and coinjection of GST-CGFELETC (SEQ ID NO: 2) with phage expressing (SEQ ID NO: 2) inhibited lung homing by 30% (Figure 3). Immunohistochemical staining of lung following administration of phage displaying a lung homing

peptide to mice revealed staining within the alveolar capillaries. No apparent preference for homing of the phage to any particular region of the lung was observed; however, no staining was observed in bronchioles luminal walls or some larger blood vessels (Example III), or in many other tissues analyzed. These results indicate that *in vivo* panning can be used to identify and analyze endothelial cell specificities within lung, thus providing a means to differentially target lung.

The invention also provides skin homing peptides such as CVALCREACGEGC (SEQ ID NO: 3; Table 5), which were identified by injection of a $CX_3CX_3CX_3C$ (SEQ ID NO: 25) cyclic library into mice (Example II). The skin homing peptide sequence CVALCREACGEGC (SEQ ID NO: 3) exhibited a 7-fold selectivity for skin over unselected phage and over background in brain and kidney (Figure 2; see, also, Table 1). Coinjection of GST-CVALCREACGEGC (SEQ ID NO: 3) with phage expressing CVALCREACGEGC (SEQ ID NO: 3) inhibited homing to skin by 55%, whereas coinjection with GST, alone, had no effect on homing (see Figure 3B). Immunohistochemical staining of skin following administration of phage displaying a skin homing peptide revealed that staining was localized to the hypodermis; no staining was observed in the dermis (Example III).

The invention further provides pancreas homing peptides such as SWCEPGWCR (SEQ ID NO: 4; Table 3). The exemplified pancreas homing molecules were identified by injection of a CX_7C (SEQ ID NO: 24) or X_2CX_4CX (SEQ ID NO: 23) cyclic library into mice (Example II). The pancreas homing peptide SWCEPGWCR

(SEQ ID NO: 4) exhibited a 20-fold selectivity for pancreas over unselected phage and over brain (Table 1; Figure 2). However, coinjection of GST-SWCEPGWCR (SEQ ID NO: 4) did not inhibit SWCEPGWCR (SEQ ID NO: 4) pancreas homing, presumably due to a conformational effect of GST on the pancreas homing peptide. Immunohistochemical staining of pancreas following administration of phage displaying a pancreas homing peptide revealed that staining was localized to the capillaries as well as larger blood vessels of the exocrine pancreas; no significant staining was observed in the endocrine vasculature (Example III). This result demonstrates that histologically and physiologically distinguishable regions within a particular organ can express unique target molecules, which provide a target for an organ homing molecule of the invention. Accordingly, the organ homing molecules of the invention provide a means to differentially targeted specific regions of a selected organ or tissue.

Retina homing peptides such as CSCFRDVCC (SEQ ID NO: 5) and CRDVVSVIC (SEQ ID NO: 6) also are provided (see Table 6). The exemplified retina homing molecules were identified by injection of a CX_7C (SEQ ID NO: 24) cyclic library into rats (Example II). The retina homing peptides CSCFRDVCC (SEQ ID NO: 5) and CRDVVSVIC (SEQ ID NO: 6), when injected individually with a control fdAMPLAY88 phage, exhibited a 3-fold and 2-fold enrichment, respectively, in retina (Example II). However, immunohistochemical staining revealed an absence of retina staining, presumably due to a relatively modest accumulation of the retina homing phage in the target tissue.

The invention also provides prostate homing peptides such as SMSIARL (SEQ ID NO: 21) and VSFLEYR (SEQ ID NO: 22), which were identified by injection of an X_7 (SEQ ID NO: 29) library into mice (Table 7). The peptides were isolated by the regular method. The prostate homing peptides SMSIARL (SEQ ID NO: 21) and VSFLEYR (SEQ ID NO: 22) exhibited a 34-fold and 17-fold enrichment, respectively, in homing to prostate as compared to brain (Table 1).

Also provided are ovary homing peptides such as RVGLVAR (SEQ ID NO: 11) and EVRSRLS (SEQ ID NO: 10), which were identified by injection of an X_7 (SEQ ID NO: 29) library into mice (Table 8). The peptides were isolated by the regular method. The ovary homing peptides RVGLVAR (SEQ ID NO: 11) and EVRSRLS (SEQ ID NO: 10) each comprised 22% of 40 clones sequenced and exhibited a 5-fold and a 3-fold enrichment, respectively, in ovary as compared to brain (Table 1).

The invention also provides adrenal gland homing peptides such as LMLPRAD (SEQ ID NO: 27) and LPRYLLS (SEQ ID NO: 28), which share a LPR motif (see Table 11), or the peptides R(Y/F)LLAGG (SEQ ID NO: 404) and RYPLAGG (SEQ ID NO: 389), which share the motif LAGG (SEQ ID NO: 430; see Table 10). The exemplified adrenal gland homing peptides were identified by injection of an X_7 (SEQ ID NO: 29) library into mice. The peptides were isolated by the regular method. The adrenal gland homing peptide LMLPRAD (SEQ ID NO: 27) exhibited a 50-fold enrichment in adrenal gland as compared to brain (Table 1).

Also provided are liver homing peptides. Such peptides were identified by injection of an X_7 (SEQ ID NO: 29) library into mice. The peptides were isolated by the regular method (see Example II, Table 1, and Table 11, below).

In addition, lymph node homing peptides, such as AGCSVTVCG (SEQ ID NO: 315) are provided (Table 9, below). Such peptides were identified by injection of an X_2CX_4CX (SEQ ID NO: 23) library into mice. The peptides were isolated by the regular method.

The invention also provides gut homing peptides such as YSGKWGK (SEQ ID NO: 9) and YSGKWGW (SEQ ID NO: 156), which were identified by injection of an X_7 (SEQ ID NO: 29) library into mice (Tables 1 and 4) and differ only in the last amino acid position. The peptides were isolated by the regular method. The gut homing peptide YSGKWGK (SEQ ID NO: 9) was present in 22% of 40 clones sequenced and was enriched 30-fold in gut as compared to brain (Table 1). In addition, gut homing peptides such as QVRRVPE (SEQ ID NO: 155) and VRRGSPQ (SEQ ID NO: 164), which share a VRR motif, were identified, as were the peptides VRRGSPQ (SEQ ID NO: 164), GGRGSWE (SEQ ID NO: 167) and FRVRGSP (SEQ ID NO: 169), which share an RGS motif.

The organ homing molecules of the invention are particularly useful as conjugates, which comprise the organ homing molecule linked to a moiety. Thus, a lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut homing molecule of the invention can be linked to a moiety, such

conjugates being useful for directing the moiety to the particular selected organ.

As used herein, the term "moiety" is used broadly to mean a physical, chemical, or biological material that is linked to an organ or tissue homing molecule. Generally, a moiety linked to an organ homing molecule imparts a biologically useful function to the homing molecule. A moiety can consist of any natural or nonnatural material for example, peptide or polypeptide sequences, organic or inorganic molecules or compositions, nucleic acid molecules, carbohydrates, lipids or combinations thereof.

A moiety can be a physical, chemical or biological material such as a virus, viral gene therapy vector, cell, liposome, microcapsule, micropump or other chambered microdevice, which can be used, for example, as a drug delivery system. Generally, such microdevices should be biologically inert and, if desired, biodegradable or excretable. Various moieties, including microcapsules, which can contain an agent, and methods for linking a moiety or chambered microdevice to an organic molecule of the invention are well known in the art and commercially available (see, for example, "Remington's Pharmaceutical Sciences" 18th ed. (Mack Publishing Co. 1990), chapters 89-91; Harlow and Lane, Antibodies: A laboratory manual (Cold Spring Harbor Laboratory Press 1988), each of which is incorporated herein by reference; see, also, Hermanson, *supra*, 1996). Additional examples of moieties are known to those skilled in the art and are intended to be included within the meaning of the term so long as

they possess a biologically useful function when linked to the homing molecules of the invention.

Linking of a moiety to an organ homing molecule for the purpose of directing the moiety to the selected organ or tissue was demonstrated by the linking of a brain homing peptide to a red blood cell (RBC), wherein the peptide directed homing of the RBC to the brain (U.S. Patent No. 5,622,699, *supra*, 1997). These results indicate that an organ or tissue homing molecule of the invention can be linked to another moiety in order to direct the moiety to a selected organ or tissue. For example, a liver homing molecule or a lung homing molecule can be linked to a nucleic acid encoding the CFTR gene and upon administration to a subject, expression of CFTR is targeted to the liver or to the lung, respectively. Similarly, a lung homing molecule can be linked to a protease inhibitor such that, upon administration of the conjugate comprising the lung homing molecule and the protease inhibitor to a subject, the protease inhibitor is targeted to the lung. Such a conjugate can be useful, for example, for treating a subject suffering from emphysema, which is characterized by excessive protease production in the lungs and autodigestion of the organ.

An organ and tissue homing molecule of the invention can be useful for directing to a selected organ or tissue a therapeutic agent, diagnostic agent or imaging agent, a tag or insoluble support, a liposome or a microcapsule comprising, for example, a permeable or semipermeable membrane, wherein an agent such as a drug to be delivered to a selected organ or tissue is contained within the liposome or

microcapsule. These and other moieties known in the art can be used in a conjugate of the invention, and in a method of the invention, as disclosed herein.

In one embodiment, a moiety can be a detectable agent such as a radionuclide or an imaging agent, which allows detection or visualization of the selected organ or tissue. Thus, the invention provides a conjugate comprising a lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut homing molecule, linked to a detectable agent. The type of detectable agent selected will depend upon the application. For example, for an *in vivo* diagnostic imaging study of the lung in a subject, a lung homing molecule can be linked to an agent that, upon administration to the subject, is detectable external to the subject. For detection of such internal organs or tissues, for example, the prostate, a gamma ray emitting radionuclide such as indium-113, indium-115 or technetium-99 can be linked to a prostate homing molecule and, following administration to a subject, can be visualized using a solid scintillation detector. Alternatively, for organs or tissues at or near the external surface of a subject, for example, retina, a fluorescein-labeled retina homing molecule can be used such that the endothelial structure of the retina can be visualized using an opthalamoscope and the appropriate optical system.

Molecules that selectively home to a pathological lesion in an organ or tissue similarly can be linked to an appropriate detectable agent such that the size and distribution of the lesion can be visualized. For example, where an organ or tissue

homing molecule homes to a normal organ or tissue, but not to a pathological lesion in the organ or tissue, the presence of the pathological lesion can be detected by identifying an abnormal or atypical image of the organ or tissue, for example, the absence of the detectable agent in the region of the lesion.

A detectable agent also can be an agent that facilitates detection *in vitro*. For example, a conjugate comprising a homing molecule linked to an enzyme, which produces a visible signal when an appropriate substrate is present, can detect the presence of an organ or tissue to which the homing molecule is directed. Such a conjugate, which can comprise, for example, alkaline phosphatase or luciferase or the like, can be useful in a method such as immunohistochemistry. Such a conjugate also can be used to detect the presence of a target molecule, to which the organ homing molecule binds, in a sample, for example, during purification of the target molecule.

In another embodiment, a moiety can be a therapeutic agent. Thus, the invention provides a conjugate comprising a lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut homing molecule linked to a therapeutic agent.

A therapeutic agent can be any biologically useful agent that, when linked to an organ homing molecule of the invention, exerts its function at the site of the selected organ or tissue. For example, a therapeutic agent can be a small organic molecule that, upon binding to a target cell due to the linked organ homing molecule, is internalized by the cell where it

can effect its function. A therapeutic agent can be a nucleic acid molecule that encodes a protein involved in stimulating or inhibiting cell survival, cell proliferation or cell death, as desired, in the selected organ or tissue. For example, a nucleic acid molecule encoding a protein such as Bcl-2, which inhibits apoptosis, can be used to promote cell survival, whereas a nucleic acid molecule encoding a protein such as Bax, which stimulates apoptosis, can be used to promote cell death of a target cell.

A particularly useful therapeutic agent that stimulates cell death is ricin, which, when linked to an organ homing molecule of the invention, can be useful for treating a hyperproliferative disorder, for example, cancer. A conjugate comprising an organ homing molecule of the invention and an antibiotic, such as ampicillin or an antiviral agent such as ribavirin, for example, can be useful for treating a bacterial or viral infection in a selected organ or tissue.

A therapeutic agent also can inhibit or promote the production or activity of a biological molecule, the expression or deficiency of which is associated with the pathology. Thus, a protease inhibitor can be a therapeutic agent that, when linked to an organ homing molecule, can inhibit protease activity at the selected organ or tissue, for example, the pancreas. A gene or functional equivalent thereof such as a cDNA, which can replenish or restore production of a protein in a selected organ or tissue, also can be a therapeutic agent useful for ameliorating the severity of a pathology. A therapeutic agent also

can be an antisense nucleic acid molecule, the expression of which inhibits production of a deleterious protein, or can be a nucleic acid molecule encoding a dominant negative protein or a fragment thereof, which can inhibit the activity of a deleterious protein.

In another embodiment, the invention provides a conjugate comprising a lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut homing molecule linked to a tag. A tag can be, for example, an insoluble support such as a chromatography matrix, or a molecule such as biotin, hemagglutinin antigen, polyhistidine, T7 or other molecules known in the art. Such a conjugate comprising a tag can be useful to isolate a target molecule, to which the organ homing molecule binds.

When administered to a subject, a conjugate comprising an organ homing molecule and a moiety is administered as a pharmaceutical composition containing, for example, the conjugate and a pharmaceutically acceptable carrier. Pharmaceutically acceptable carriers are well known in the art and include, for example, aqueous solutions such as water or physiologically buffered saline or other solvents or vehicles such as glycols, glycerol, oils such as olive oil or injectable organic esters.

A pharmaceutically acceptable carrier can contain physiologically acceptable compounds that act, for example, to stabilize or to increase the absorption of the complex. Such physiologically acceptable compounds include, for example, carbohydrates, such as

glucose, sucrose or dextrans, antioxidants, such as ascorbic acid or glutathione, chelating agents, low molecular weight proteins or other stabilizers or excipients. One skilled in the art would know that the choice of a pharmaceutically acceptable carrier, including a physiologically acceptable compound, depends, for example, on the route of administration of the composition. The pharmaceutical composition also can contain an agent such as a cancer therapeutic agent or other therapeutic agent as desired.

One skilled in the art would know that a pharmaceutical composition containing an organ homing molecule can be administered to a subject by various routes including, for example, orally or parenterally, such as intravenously. The composition can be administered by injection or by intubation. The pharmaceutical composition also can be an organ homing molecule linked to a moiety such as a liposome or other polymer matrix, which can have incorporated therein, for example, a drug that promotes or inhibits cell death (Gregoriadis, Liposome Technology, Vol. 1 (CRC Press, Boca Raton, FL 1984), which is incorporated herein by reference). Liposomes, for example, which consist of phospholipids or other lipids, are nontoxic, physiologically acceptable and metabolizable carriers that are relatively simple to make and administer.

In performing a diagnostic or therapeutic method as disclosed herein, an effective amount of a conjugate comprising an organ homing molecule must be administered to the subject. An "effective amount" is the amount of the conjugate that produces a desired

effect. An effective amount will depend, for example, on the moiety linked to the organ homing molecule and on the intended use. For example, a lesser amount of a radiolabeled homing molecule can be required for imaging as compared to the amount of the radiolabeled molecule administered for therapeutic purposes, where cell killing is desired. An effective amount of a particular conjugate for a specific purpose can be determined using methods well known to those in the art.

The route of administration of an organ molecule will depend, in part, on the chemical structure of the organ homing molecule. Peptides, for example, are not particularly useful when administered orally because they can be degraded in the digestive tract. However, methods for chemically modifying peptides to render them less susceptible to degradation by endogenous proteases or more absorbable through the alimentary tract are well known (see, for example, Blondelle et al., *supra*, 1995; Ecker and Crooke, *supra*, 1995; Goodman and Ro, *supra*, 1995). Such methods can be performed on peptides that home to a selected organ or tissue. In addition, methods for preparing libraries of peptide analogs such as peptides containing D-amino acids; peptidomimetics consisting of organic molecules that mimic the structure of a peptide; or peptoids such as vinylogous peptoids, have been previously described above and can be used to identify homing molecules suitable for oral administration to a subject.

The invention provides methods of identifying a selected organ or tissue by administering to a

subject a conjugate comprising a lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut and a detectable agent. A conjugate comprising an organ homing molecule of the invention linked to a detectable moiety conjugate can be administered to a subject and used to identify or visualize a selected organ or tissue. The ability to visualize an organ, particularly an internal organ, provides a means diagnose a pathology of the selected organ or tissue. For example, a prostate homing molecule linked to indium-113 can be administered to a subject in order to image the prostate. Such a method can be particularly valuable because methods for imaging the prostate are limited. The presence of a prostate pathology can be revealed by detecting that a region of the prostate does not contain the conjugate, thus indicating an abnormality in circulation to the region, or by detecting that the prostate is abnormally enlarged or lacking its normal boundaries. For organs or tissues such as retina, which can be visualized directly using an ophthalmoscope, a conjugate comprising a retina homing molecule linked to fluorescein can be administered to a subject and used to examine the vascular integrity and circulation in the retina. The absence of a normal or typical pattern of retinal image can indicate the presence of a retinal pathology in the region. For example, an abnormal retinal pattern can reflect vascular changes indicative of a hyperproliferative or degenerative pathology.

In principle, an organ homing molecule of the invention can have an inherent biological property, such that administration of the molecule provides direct biological effect. For example, an organ homing

molecule can be sufficiently similar to a naturally occurring ligand for the target molecule that the organ homing molecule mimics the activity of the natural ligand. Such an organ homing molecule can be useful as a therapeutic agent having the activity of the natural ligand. For example, where the organ homing molecule mimics the activity of a growth factor that binds a receptor expressed by the selected organ or tissue, such as a skin homing molecule that mimics the activity of epidermal growth factor, administration of the organ homing molecule can result in cell proliferation in the organ or tissue. Such inherent biological activity of an organ homing molecule of the invention can be identified by contacting the cells of the selected organ or tissue with the homing molecule and examining the cells for evidence of a biological effect, for example, cell proliferation or, where the inherent activity is a toxic effect, cell death.

In addition, an organ homing molecule of the invention can have an inherent activity of binding a particular target molecule such that a corresponding ligand cannot bind the receptor. It is known, for example, that various types of cancer cells metastasize to specific organs or tissues, indicating that the cancer cells express a ligand that binds a target molecule in the organ to which it metastasizes. Thus, administration of a lung homing molecule, for example, to a subject having a tumor that metastasizes to lung, can provide a means to prevent the potentially metastatic cancer cell from becoming established in the lung. In general, however, the organ homing molecules of the invention are particularly useful for targeting a moiety to a selected organ or tissue, particularly to

lung, skin, pancreas, retina, prostate, ovary, lymph node, adrenal gland, liver or gut. Thus, the invention provides methods of treating a pathology in a selected organ or tissue by administering to a subject having the pathology a conjugate comprising an organ homing molecule of the invention linked to a therapeutic agent.

Specific disorders of the lung, for example, can be treated by administering to a subject a conjugate comprising a lung homing molecule linked to a therapeutic agent. Since a lung homing molecule of the invention can localize to the capillaries and alveoli of the lung, disorders associated with these regions are especially amenable to treatment with a conjugate comprising the lung homing molecule. For example, bacterial pneumonia often originates in the alveoli and capillaries of the lung (Rubin and Farber, Pathology 2nd ed., (Lippincott Co.,1994)). Thus, a lung homing molecule conjugated to a suitable antibiotic can be administered to a subject to treat the pneumonia. Similarly, cystic fibrosis causes pathological lesions in the lung due to a defect in the CFTR. Thus, administration of a lung homing molecule conjugated to a nucleic acid molecule encoding the CFTR provides a means for directing the nucleic acid molecule to the lung as an *in vivo* gene therapy treatment method.

The invention also provides methods of treating a pathology of the skin by administering to a subject having the pathology a conjugate comprising a skin homing molecule and a therapeutic agent. For example, a burn victim can be administered a conjugate comprising a skin homing molecule linked to epithelial

growth factor or platelet derived growth factor such that the growth factor is localized to the skin where it can accelerate regeneration or repair of the epithelium and underlying dermis. Furthermore, a method of the invention can be useful for treating skin pathologies caused by bacterial infections, particularly infections that spread through the hypodermis and dermis or that are localized in these regions, by administering to a subject a conjugate comprising a skin homing molecule linked to an antibiotic.

The invention also provides methods of treating a pathology of the pancreas by administering to a subject having the pathology a conjugate comprising a pancreas homing molecule linked to a therapeutic agent. In particular, since a pancreas homing molecule of the invention can localize to the exocrine pancreas, a pathology associated with the exocrine pancreas can be treated and, in some cases, may not adversely affect the endocrine pancreas. A method of the invention can be particularly useful to treat acute pancreatitis, which is an inflammatory condition of the exocrine pancreas caused by secreted proteases damaging the organ. A conjugate comprising a pancreas homing molecule linked to a protease inhibitor can be used to inhibit the protease mediated destruction of the tissue, thus reducing the severity of the pathology. Appropriate protease inhibitors useful in such a conjugate are those that inhibit enzymes associated with pancreatitis, including, for example, inhibitors of trypsin, chymotrypsin, elastase, carboxypeptidase and pancreatic lipase. A method of the invention also can be used to treat a subject

having a pancreatic cancer, for example, ductal adenocarcinoma, by administering to the subject a conjugate comprising a therapeutic agent linked to a molecule that homes to pancreas.

The methods of the invention also can be used to treat a pathology of the eye, particularly the retina, by administering to a subject having the pathology a conjugate comprising a retina homing molecule linked to a therapeutic agent. For example, proliferative retinopathy is associated with neovascularization of the retina in response to retinal ischemia due, for example, to diabetes. Thus, administration of a conjugate comprising a retina homing molecule linked to a gene that stimulates apoptosis, for example, Bax, can be used to treat the proliferative retinopathy. Similarly, methods of the invention can be used to diagnose or treat prostate, ovary, lymph node, adrenal gland, liver, or gut pathology using the appropriate organ or tissue homing molecules disclosed herein either alone, or linked to a desired moiety.

An organ or tissue homing molecule is useful, for example, for targeting a therapeutic or detectable agent to the selected organ or tissue. In addition, an organ or tissue homing molecule can be used to identify the presence of a target molecule in a sample. As used herein, the term "sample" is used in its broadest sense to mean a cell, tissue, organ or portion thereof that is isolated from the body. A sample can be, for example, a histologic section or a specimen obtained by biopsy or cells that are placed in or adapted to tissue culture. If desired, a sample can be processed, for

example, by homogenization, which can be an initial step for isolating the target molecule to which an organ or tissue homing molecule binds.

An organ homing molecule obtained as disclosed herein can be useful for identifying the presence of a target molecule, particularly a cell surface protein, that is recognized by the homing molecule, or for substantially isolating the target molecule. Thus, the invention provides methods of identifying target molecules that selectively bind a lung homing molecule, a skin homing molecule, a pancreas homing molecule, a retina homing molecule, a prostate homing molecule, an ovary homing molecule, a lymph node homing molecule, an adrenal gland homing molecule, a liver homing molecule or a gut homing molecule. Such a method comprises contacting a sample of the selected organ or tissue, for example, prostate, with a prostate homing molecule, and detecting selective binding of a component of a sample, wherein such binding identifies the presence of a target molecule.

An organ or tissue homing molecule such as a prostate homing peptide can be linked to a tag, for example, a solid support such as a chromatography matrix. The immobilized organ homing molecule then can be used for affinity chromatography by passing an appropriately processed sample of prostate tissue over a column containing the matrix under conditions that allow specific binding of the prostate homing molecule to the particular target molecule (see, for example, Deutshcer, Meth. Enzymol., Guide to Protein Purification (Academic Press, Inc., ed. M.P. Deutscher,

1990), Vol. 182, which is incorporated herein by reference; see, for example, pages 357-379). Unbound and nonspecifically bound material can be removed and the target molecule, which forms a complex with the prostate homing molecule, can be eluted from the column and collected in a substantially isolated form. The substantially isolated prostate target molecule then can be characterized using well known methods. An organ or tissue homing molecule also can be linked to a detectable agent such as a radionuclide, a fluorescent molecule, an enzyme or a labeled biotin tag and can be used, for example, to screen a sample in order to detect the presence of the target molecule or to follow the target molecule during its isolation.

As an alternative to using an organ or tissue sample to identify a target molecule of the selected organ or tissue, extracts of cultured cells derived from the selected organ or tissue, or extracts of cultured endothelial cells can be used as the starting material. Selection of cells containing the target molecule can be determined by using binding and cell attachment assays (see Barry et al., Nature Med. 2:299-305 1996), which is incorporated herein by reference). Those cells containing the target molecule can be used to prepare extracts for the isolation and identification of a target molecule, as described above.

Upon identifying an appropriate cell line expressing the target molecule, the target molecule can be labeled by growing the cells in medium containing radiolabeled amino acids. The radiolabeled amino acids are incorporated into the target molecule, thus

facilitating its identification during purification. Labeled cells then can be extracted with octylglucoside and the extract can be fractionated by affinity chromatography using a pancreas homing molecule coupled to a matrix such as Sepharose. Extracts prepared, for example, from human umbilical vein endothelial cells can be used as a control. The purified target molecule then can be microsequenced and antibodies can be prepared. If desired, oligonucleotide probes can be prepared and used to isolate cDNA clones encoding the target receptor. Alternatively, an anti-receptor antibody can be used to isolate a cDNA clone from an expression library (see Argraves et al., J. Cell Biol. 105:1183-1190 (1987), which is incorporated herein by reference).

In addition to biochemically isolating a target molecule, a nucleic acid encoding the target molecule can be isolated by using, for example, a pancreas homing molecule as a chemical probe to screen a pancreatic cDNA expression library for clones that express the target molecule. For example, bacteria expressing a pancreatic cDNA library can be attached to a membrane, lysed, and screened with a pancreas homing molecule conjugated, for example, to an enzyme that produces a colorimetric or fluorescent signal. Bacterial clones expressing a target molecule are identified and the cDNA encoding the target molecule can be isolated. Additionally, a mammalian cell expression cloning system such as the COS cell system can be used to identify a target molecule. For example, a cDNA library can be prepared using mRNA from primary pancreas cells which can be cloned into an expression vector. Cells expressing a cDNA encoding

the target molecule then can be selected using the pancreas homing peptide as a probe, for example, by panning of cell clones against pancreas homing peptide attached to a plate. Alternatively, phage can be used to display the pancreas homing peptide and can be attached to magnetic beads coated, for example, with anti-M13 antibodies (Pharmacia). Cells expressing the target molecule that bind to the pancreas homing peptide then can be recovered and the plasmids encoding the receptor can be isolated. The recovered plasmid preparations can be divided into pools and examined in COS cell transfections. The procedure can be repeated until single plasmids are obtained that enable the COS cells to bind the pancreas homing peptide.

The present invention also provides a method of identifying a MDP-binding homing molecule that selectively homes to lung endothelium. The method includes the steps of contacting membrane dipeptidase (MDP) with one or more molecules; and determining specific binding of a molecule to the MDP, where the presence of specific binding identifies the molecule as a MDP-binding homing molecule that selectively homes to lung endothelium. In a method of the invention, the membrane dipeptidase can be substantially purified and can be, for example, immobilized to a support. The membrane dipeptidase can be any mammalian MDP, for example, human MDP having SEQ ID NO: 448.

As disclosed herein, the CGFECVRQCPERC (SEQ ID NO: 1) peptide can selectively bind to mouse lung vasculature after intravenous injection (Example IIA). Furthermore, as disclosed in Example IVB, a 55 kDa lung cell surface protein that selectively binds GFE-1

(CGFECVRQCPERC; SEQ ID NO: 1) was isolated from rat lung extracts using affinity chromatography. Tryptic digestion and sequencing by mass spectrometry revealed that two peptides derived from the 55 kDa protein were completely identical to portions of rat membrane dipeptidase (EC 3.4.13.19). Further experimentation demonstrated that GFE-1 (SEQ ID NO: 1) affinity purified fractions of rat lung cell extracts have membrane dipeptidase activity, as indicated by the time-dependent conversion of the specific MDP substrate Gly-D-Phe to D-Phe (Example IVC and Figure 5). Furthermore, binding of GFE-1 phage (CGFECVRQCPERC; SEQ ID NO: 1) and, to a lesser extent, GFE-2 phage (CGFELETC; SEQ ID NO: 2) to COS cells transfected with membrane dipeptidase was significantly higher than the binding of phage bearing an unrelated peptide sequence (Example IVD and Figure 6B), indicating that membrane dipeptidase is the GFE-1 (SEQ ID NO: 1) receptor.

Thus, as disclosed herein, the lung metalloprotease, membrane dipeptidase, serves as the receptor for the selective homing of molecules to lung endothelium. An exemplary class of molecules that selectively home to lung endothelium by targeting membrane dipeptidase is the class of peptides bearing a GFE motif, for example, CGFECVRQCPERC (SEQ ID NO: 1).

Membrane dipeptidase, also known as renal dipeptidase, microsomal dipeptidase, dehydropeptidase-1, or MDP and currently classified as EC 3.4.13.19 (previously EC 3.4.13.11), is a plasma membrane glycosyl phosphatidylinositol-anchored glycoprotein (Keynan et al., in Hooper (Ed.) Zinc Metalloproteases in Health and Disease Taylor and

Francis, London pages 285-309 (1996), which is incorporated herein by reference). This zinc metalloprotease, which is expressed mainly in lung and kidney brush border, is involved *in vivo* in renal metabolism of glutathione and in pulmonary metabolism of peptidyl leukotrienes. In addition, MDP is the only known example of a mammalian β-lactamase. MDP forms a disulfide-linked homodimer, with the molecular weight of the monomer ranging from about 48 to 59 kDa depending on the species of origin (Keynan et al., Biochem. 35:12511-12517 (1996), which is herein incorporated by reference; see, also, Example IVB).

Membrane dipeptidase expression has been detected in several tissues although it is expressed mainly in lung and kidney. There have been reports of low levels of MDP activity in total extracts from liver, spleen, small intestine and brain, while others have found no detectable activity in these organs. In the mouse, four distinct MDP mRNAs are present, and they are differentially expressed in several organs (Habib et al., J. Biol. Chem. 271:16273-16280 (1996)). Organ-specific differences in the nature and extent of pig MDP N-linked glycosylation also have been reported (Hooper et al., Biochem. J. 324:151-157 (1997)).

In the kidney, MDP expression is restricted to epithelial cells in the brush border region of the proximal tubules. In the lung, MDP expression has been detected in many cell types including endothelial cells as well as epithelial cells of the conducting airways, alveolar ducts, capillaries, and the basement membrane of alveoli and terminal bronchioles (Habib et al., *supra*, 1996); Inamura et al., Prostaglandins

Leukotrienes and Essential Fatty Acids 50:85-92 (1994)). MDP expression also has been observed on endothelial cells of submucosal microvessels in the human trachea (Yamaya et al., Resp. Physiol. 111:101-109 (1998)). The level of MDP activity is highest in lung (Hirota et al., Eur. J. Biochem. 160:521-525 (1986); Habib et al., Proc. Natl. Acad. Sci. USA 95:4859-4863 (1998)). This expression pattern correlates with the strong lung homing of molecules such as GFE-1 (SEQ ID NO: 1).

As used herein, the term "membrane dipeptidase" is synonymous with "MDP" and refers to the enzyme currently classified as EC 3.4.13.19 (previously EC 3.4.13.11) and also known as renal or microsomal dipeptidase or dehydropeptidase-1. The term membrane dipeptidase encompasses any mammalian membrane dipeptidase, for example, the human, pig, mouse, rat and rabbit homologs having the amino acid sequences shown as SEQ ID NOS: 448 to 452 in Figure 9 as well as related polypeptides having substantial amino acid sequence similarity to one of these polypeptides. Such related polypeptides will exhibit greater sequence similarity to SEQ ID NO: 448, 449, 450, 451 or 452 than to other zinc metalloproteases or peptidases such as dipeptidyl peptidase IV and include alternatively spliced forms of MDP and isotype variants of the amino acid sequences shown in Figure 9. Thus, the term MDP encompasses homologous polypeptides obtained from different mammalian species as well as other variants and related polypeptides that generally have amino acid identities of greater than about 65%, preferably greater than about 70% and more preferably greater than about 80% or 90% with SEQ ID NO: 448, 449, 450, 451 or

452. A method of the invention preferably uses human membrane dipeptidase (SEQ ID NO: 448).

The term "substantially purified," as used herein in reference to a membrane dipeptidase polypeptide, means that the polypeptide is in a form that is relatively free from contaminating lipids, nucleic acids, unrelated polypeptides and other cellular material normally associated with membrane dipeptidase in a cell.

The methods of the invention for identifying a MDP-binding homing molecule can be practiced *in vivo* or *in vitro,* and membrane dipeptidase can be obtained from a number of sources. Sources of membrane dipeptidase include whole cells or cell extracts containing endogenous or exogenous MDP. Additional sources of MDP include partially purified cell extracts; biochemically purified enzyme, for example, affinity purified MDP; recombinant polypeptides; and transfected cell lines.

Affinity chromatography can be particularly useful for purifying or partially purifying membrane dipeptidase for use in a method of the invention. For example, membrane dipeptidase can be purified from lung cell extracts by affinity chromatography using immobilized GFE-1 peptide (SEQ ID NO: 1) as described for murine and rat membrane dipeptidase in Example IVC. Similarly, membrane dipeptidase can be obtained by affinity chromatography using other immobilized ligands such as cilastatin. For example, membrane dipeptidase can be efficiently purified in two steps, through selective release of MDP by bacterial phosphatidyl

inositol-specific phospholipase C (PI-PLC) coupled with cilastatin-Sepharose affinity chromatography as described in Littlewood et al., Biochem. J. 257:361-367 (1989); and Campbell et al., J. Biol. Chem. 259:14586-14590 (1984), each of which is incorporated herein by reference.

Recombinant membrane dipeptidase also can be useful in a method of the invention. The amino acid and nucleic acid sequences of a variety of MDP homologs are known in the art. Nucleic acid sequences encoding the membrane dipeptidase polypeptides shown in Figure 9 can be obtained, for example, from databases such as GenBank or from the literature (see, for example, GenBank Accession Numbers D13139 and 285150; Adachi et al., J. Biol. Chem. 265:3992-3995 (1990); Rached et al., 1990; Keynan et al., FEBS Letts. 349:50-54 (1994); Satoh et al., Biochim. Biophys. Acta 1163:234-242 (1993); Adachi et al., Biochim. Biophys. Acta 1132:311-314 (1992); An et al., Biochim. Biophys. Acta 1226:337-340 (1994); and Igarashi and Karniski, Biochem. J. 280:71-78 (1991), each of which is incorporated herein by reference). Novel membrane dipeptidase cDNAs can be isolated from additional mammalian species with a nucleotide sequence as a probe or primer using methods well known in the art of molecular biology (Innis et al. (Ed.), PCR Protocols, San Diego: Academic Press, Inc. (1990); Erlich, *supra,* 1989; Sambrook et al., *supra,* 1989, each of which is incorporated herein by reference). One skilled in the art knows a variety of methods for expression of MDP encoding nucleic acids and subsequent isolation of recombinant MDP polypeptide.

In the methods of the invention for identifying a MDP-binding homing molecule that selectively homes to lung endothelium, specific binding of a molecule to MDP identifies the molecule as a MDP-binding homing molecule that selectively homes to lung endothelium. The term "specific binding," as used herein in reference to a molecule and MDP, means that the molecule has an affinity for MDP that is measurably different from a non-specific interaction. Specific binding can be measured, for example, by determining binding of a molecule compared to binding of a control molecule, which generally is a molecule of similar structure that does not have binding activity, for example, a peptide of similar size that lacks a GFE motif. In this case, specific binding is indicated if the molecule has measurably higher affinity for membrane dipeptidase than the control molecule. Specificity of binding also can be determined, for example, by competition with a control molecule that is known to bind to MDP, for example, a peptide containing the GFE motif.

The term specific binding, as used herein, includes both low and high affinity specific binding. Specific binding can be exhibited, for example, by a low affinity MDP-binding homing molecule having a Kd for membrane dipeptidase of about 10^{-4} M to about 10^{-7} M. Specific binding also can be exhibited by a high affinity MDP-binding homing molecule, for example, a MDP-binding homing molecule having a Kd for membrane dipeptidase of at least about 10^{-7} M, at least about 10^{-8} M, at least about 10^{-9} M, at least about 10^{-10} M, or at least about 10^{-11} M or 10^{-12} M or greater. A MDP-binding homing peptide including the sequence

X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids, can have, for example, a Kd for membrane dipeptidase of about 2 x 10^{-5} M to 10^{-7} M, for example, a Kd of about 10^{-6} to 10^{-7} M. Both low and high affinity MDP-binding homing molecules that selectively home to lung endothelium can be useful in selectively directing a moiety to lung endothelium in a subject as described further below.

A variety of art known techniques can be used to determine specific binding of a molecule to membrane dipeptidase according to a method of the invention. Conditions suitable for specific binding are described, for example, in Example IVB. Specific binding also can be determined by transfecting cells lacking MDP expression with MDP as described, for example, in Example IVD. In this case, specific binding is determined, in part, by significantly higher binding of a molecule to the MDP-transfected cells than to untransfected cells.

The present invention is directed to the surprising discovery that MDP-binding molecules home specifically to the lung vasculature in spite of MDP expression in other tissues such as kidney. As disclosed herein, injection of MDP-binding GFE-1 (SEQ ID NO: 1) bearing phage into the mouse circulation resulted in rapid binding of the phage to lung microvasculature with some diffuse staining on neighboring cells. The same results were obtained by injecting GFE-1 (SEQ ID NO: 1) bearing phage into rat circulation. In particular, the MDP-binding GFE-1 phage did not bind, for example, to the brush border of kidney proximal tubules, which expresses high levels of

MDP. These results indicate that expression of MDP on the luminal surface of lung endothelial cells can mediate homing of MDP-binding phage from the circulation to lung endothelium, while MDP-binding phage cannot access and home to kidney MDP. Thus, MDP mediates selective homing of molecules to lung endothelium in preference to other endothelial cells.

Selective homing of GFE-1 (SEQ ID NO: 1) bearing phage to lung vasculature further demonstrates that a moiety such as a phage can be linked to a MDP-binding homing molecule and thereby selectively directed to lung endothelium. Thus, the present invention provides methods of selectively targeting moieties, such as phage, gene therapy vectors or antibiotics, to lung endothelium for treatment of lung disorders.

A method of the invention for selectively directing a moiety to lung endothelium in a subject involves administering to the subject a conjugate containing a moiety linked to a MDP-binding homing molecule that selectively homes to lung endothelium, whereby the moiety is selectively directed to lung endothelium in the subject. The MDP-binding homing molecule is identified by contacting membrane dipeptidase (MDP) with one or more molecules; and determining specific binding of a molecule to the MDP, where the presence of specific binding identifies the molecule as a MDP-binding homing molecule that selectively homes to lung endothelium. A method of the invention can be useful for targeting genes or medications to the lung in a subject suffering, for example, from pneumonia; asthma; emphysema; respiratory

infection; chronic bronchitis; chronic interstitial lung disease; lung cancer; pleurisy or cystic fibrosis. If desired, a method of the invention can be used prophylactically, for example, to selectively direct a moiety to the lung endothelium of an individual with a family history of a lung disorder, for example, or an individual susceptible to lung infection.

A moiety to be selectively directed to lung endothelium can be a physical, chemical or biological material such as a virus, viral gene therapy vector, cell, liposome, microcapsule, micropump or other chambered microdevice, which can be used, for example, as a drug delivery system. Such microdevices generally are biologically inert and, if desired, can be biodegradable or excretable. Various moieties, including microcapsules, which can contain an agent, and methods for linking a moiety or chambered microdevice to an organic molecule are well known in the art and commercially available as described hereinabove. Exemplary moieties that can be linked to a MDP-binding homing molecule that selectively homes to lung endothelium to produce a therapeutic conjugate include therapeutic antimicrobial bacteriophage; antibiotics such as ampicillin; and antiviral agents such as ribavirin (see above).

A moiety to be selectively directed to lung endothelium according to a method of the invention can be, for example, a therapeutic bacteriophage ("phage"). Phage have been shown to be nontoxic (Ochs et al., J. Clin. Invest. 50:2559-2568 (1971), which is incorporated herein by reference), and the use of phage therapy is known in the art for treatment of bacterial

infections such as antibiotic-resistant infections (Barrow and Soothill, Trends in Microbiology 5:268-271 (1997); Slopek et al., Arch. Immunol. Ther. Exp. 35:553-561 (1987); and Merrill et al., Proc. Natl. Acad. Sci., USA 93:3188-3192 (1996), each of which is incorporated herein by reference; see, also, Practical Applications of Bacteriophages CRC Press, Boca Raton, Florida). For example, in a series of 550 patients, the majority of whom had been unsuccessfully treated with antibiotic therapy, phage therapy resulted in 75-100% success in ameliorating a variety of infections including respiratory tract suppurative infections and broncopneumonia (Slopek et al., *supra*, 1987). Phage therapy can be particularly useful in treating nosocomial and multi-drug-resistant infections.

Studies have shown that both prophylaxis and treatment are possible using fewer phage than inoculating bacteria, indicating that phage multiply *in vivo*. Thus, phage therapy can be more effective than conventional treatment with antibiotics, such as streptomycin, tetracycline, ampicillin and sulfafurazole, because of the ability of phage to replicate *in vivo*. If desired, treatment with a phage conjugate containing a MDP-binding homing molecule can be combined with antibiotic drug therapy.

Preferably, a phage moiety to be selectively directed to lung endothelium is a lytic phage. Such a phage can be readily modified by standard genetic techniques to encode a MDP-binding homing peptide such as GFE-1 (SEQ ID NO: 1) to produce a conjugate that is selectively directed to lung endothelium. Phage useful in the methods of the invention include, for example,

T4-related phage, also known as members of the "T-Even family of phages." One skilled in the art understands that a phage moiety is selected with a receptor specificity for the bacteria characteristic of an infection to be treated, for example, phage with receptor specificity for *Staphylococcus, Klebsiella, Proteus, Escherichia, Shigella, Pseudomonas* or *Salmonella*. If desired, the pathogenic bacteria can be typed and monitored for phage sensitivity. For treatment of resistant bacteria, a phage conjugate can include, if desired, a mixture of phage with different receptor specificities against a variety of types of bacteria.

A phage/MDP-binding homing conjugate can be administered to a subject, for example, intravenously. Such a conjugate also can be administered orally, for example, as 10 ml sterile phage lysate half an hour before each meal, with gastric juices neutralized by Vichy water, baking soda or gelatin. After oral administration, phage/MDP-binding homing conjugates access the blood and subsequently are selectively directed to lung endothelium. Administration can be repeated, if needed, daily over a period of several weeks or months. An appropriate dose of a phage conjugate can readily be determined by the skilled person and generally will be in the range of about 100 to about 10^{10} plaque forming units (pfu), usually from about 100 to 10^{6} pfu.

A moiety to be selectively directed to lung endothelium for gene therapy can be a gene therapy vector. As used herein, the term "gene therapy vector" means a vector containing a nucleic acid component,

which, when delivered to host cells, transiently or permanently expresses an encoded gene product in the host cells *in vivo*.

A variety of gene therapy vectors that can be selectively directed to lung endothelium using an MDP-binding homing molecule also are known in the art, including viral and non-viral vectors, for example, retroviral vectors, adenoviral vectors, adeno-associated vectors (AAV), herpesvirus vectors and liposome plasmid vectors (Chang, Somatic Gene Therapy CRC Press, Boca Raton, Florida (1995), each of which is incorporated herein by reference). Retroviral and AAV vectors can be useful, for example, for permanent expression, while adenovirus, herpesvirus and liposome-plasmid vectors generally give transient expression. Adenoviral vectors, for example, have been used to express the cystic fibrosis transmembrane receptor (CFTR) and recombinant α1-antitrypsin in lung (Rosenfeld et al., Cell 68:143 (1992); Rosenfeld et al., Science 252: 431 (1991), each of which is incorporated herein by reference). Liposome DNA complexes also have been used to effect gene transfer to the lung (see, for example, Zhu et al., Science 261:209 (1993), which is incorporated herein by reference). Phage vectors also can be useful for expressing a desired nucleic acid *in vivo* (see, for example, Ivanenkov et al., Biochimica et Biophysica Acta 1448:450-462 (1999); Ivanekov et al., Biochimica et Biophysica Acta 1448:463-472 (1999), each of which is incorporated by reference herein).

The methods of the invention for selectively directing a moiety to lung endothelium using a

conjugate containing a MDP-binding homing molecule such as GFE-1 (SEQ ID NO: 1) can be useful in the therapeutic management of a variety of pulmonary disorders. For example, by selectively directing a gene therapy vector encoding a cytokine to lung endothelium, the methods of the invention can be useful for immunotherapy. A variety of cytokines or chemokines can be useful in stimulating an immune response, such as an anti-cancer or anti-viral immune response, when administered according to a method of the invention. Such cytokines and chemokines include GM-CSF, G-CSF, IFN-γ, IFN-α, TNF-α, TNF-β, IL-1. IL-2, IL-3, IL-4, IL-6, IL-7, IL-10, IL-12, lymphotactin or DC-CK1 (Pardoll, Annu. Rev. Immunol. 13:399-415 (1995; Hunt et al., J. Immunotherapy 14:314-321 (1993); Chang, *supra,* 1995, each of which is incorporated herein by reference). The methods of the invention can be more effective than administration of recombinant cytokines, due to the short half-life of cytokines in the circulation and the lack of their targeting to lung.

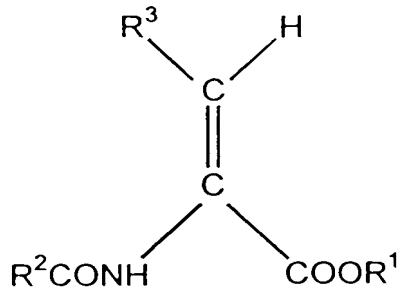
As discussed above, the methods of the invention can be useful for treating pulmonary infections by selectively directing a phage moiety or an antibiotic drug such as streptomycin, tetracycline, ampicillin or sulfafurazole to lung endothelium. For example, the methods of the invention can be useful for treating infections secondary to acquired immunodeficiency syndrome (AIDS) or cystic fibrosis.

The methods of the invention for selectively directing a moiety to lung endothelium also can be used for replacement gene therapy of lung disorders such as α1-antitrypsin deficiency and cystic fibrosis (Alton

and Geddes, Brit. J. Hosp. Medicine 58:38-40 (1997); Wood, Radiology 204:1-10 (1997), each of which is incorporated herein by reference). Genes encoding wild type α1-antitrypsin (α1-AT) and the cystic fibrosis transmembrane receptor (CFTR) have been isolated (Riordan et al., Science 245:1066-1073 (1989); Rich et al., Nature 347:358-63 (1990; Rosenfeld et al., Science 252:431-434 (1991), each of which is incorporated herein by reference) and can be transferred selectively to the lung in a gene therapy vector linked to a MDP-binding homing molecule such as GFE-1 (SEQ ID NO: 1).

In one embodiment, the invention provides a method for selectively directing a moiety to lung endothelium where the MDP-binding homing molecule is a peptide including the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids. Such a MDP-binding homing peptide can include, for example, the sequence CGFECVRQCPERC (SEQ ID NO: 1) or CGFELETC (SEQ ID NO: 2).

In another embodiment, the invention provides a method for selectively directing a moiety to lung endothelium where the MDP-binding homing molecule contains the following Structure 1:



where R^2 and R^3 are hydrocarbon radicals in the range respectively of 3-10 and 1-15 carbon atoms; in either one of these R^2 or R^3 hydrocarbon chains 1-6 hydrogens may be replaced by halogens or a nonterminal methylene may be replaced by oxygen or sulfur, including oxidized forms of the latter; additionally, a terminal hydrogen in R^3 can also be replaced by hydroxyl or thiol, which may be acylated or carbamoylated; or the hydrogen can be replaced by amino, which may be derivatized as in an acylamino, ureido, amidino, quanidino, or alkyl or substituted amino group, including quaternary nitrogen grouping; or, there may be replacement by acid groups such as carboxylic, phosphonic or sulfonic acid groups or esters or amides thereof, or cyano; or combinations thereof, such as a terminal amino acid grouping; and R^1 is hydrogen or lower alkyl (C_{1-6}) or dialkylaminoalkyl, or a pharmaceutically acceptable cation. Such an MDP-binding homing molecule can be, for example, 7-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid, also known as cilastatin.

An MDP-binding homing molecule can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl

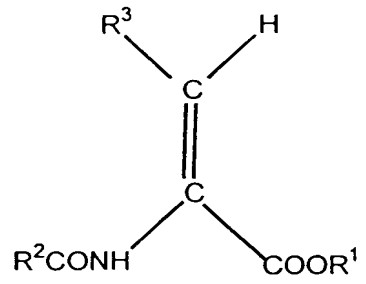
with a limitation that the carbon adjacent to the carbonyl cannot be tertiary.

An MDP-binding homing molecule also can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl with a limitation that the carbon adjacent to the carbonyl cannot be tertiary, and in which R^3 is n-alkyl (1-9 carbons) or n-alkyl (1-9 carbons) having a terminal substituent which is a quaternary nitrogen, amine derivative or amino acid derived group. An MDP-binding homing molecule can be, for example, a compound having Structure 1 in which R^2 is 2,2-dimethylcyclopropyl or 2,2-dichlorocyclopropyl and in which R^3 is a hydrocarbon chain of 3 to 7 carbon atoms without a terminal substituent or having a terminal substituent which is trimethylammonium, amidino, guanidino or 2-amino-2-carboethylthio.

Exemplary MDP-binding homing molecules having Structure 1 useful in the invention include the following: Z-2-(2,2-dimethylcyclopropane carboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dichlorocyclo propanecarboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dimethylcyclopropane carboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-

guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-ureido-2-octenoic acid; Z-8-(l-2-amino-2-carboxy ethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-octenoic acid; Z-2-(2,2-dimethylcyclopropane carboxamido)-2-octenoic acid (racemic and dextrorotatory forms); Z-2-(2,2-dichloro cyclopropanecarboxamido)-2-octenoic acid;7-(L-2-amino-2-carboxyethylthio) -2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid; and 6-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-hexenoic acid.

As set forth above, the methods of the invention for targeting treatment to the lungs can be practiced with an MDP-binding homing molecule, which is a Z-2-acylamino- 3-monosubstituted propenoate having Structure 1,



where R^2 and R^3 are hydrocarbon radicals in the range respectively of 3-10 and 1-15 carbon atoms. In either of these hydrocarbon radicals R^2 and R^3, up to 6 hydrogens may be replaced by halogens, or a non-terminal methylene may be replaced by oxygen or sulfur, including oxidized forms of the latter.

A terminal hydrogen in R^3 also can be replaced by a hydroxyl or thiol group, which may be acylated, such as with an alkanoyl acid of 1-8 carbon atoms, or carbamoylated, including alkyl and dialkyl carbamate derivatives; or the hydrogen can be replaced by an amino group, which may be derivatized as in an acylamino, ureido, amidino, guanidino, or alkyl or substituted alkyl amino group, including quaternary nitrogen groupings; or, alternatively, there may be replacement by acid groups such as carboxylic, phosphonic or sulfonic acid groups or esters or amides thereof, as well as cyano; or combinations thereof, such as a terminal amino acid grouping.

In an MDP-binding homing molecule having Structure 1, R^2 is preferably a branched alkyl or cycloalkyl radical (C_{3-10}), with a limitation that the carbon adjacent to the carbonyl cannot be tertiary. R^2 cannot be phenyl or straight chain lower alkyl of 1-4 carbon atoms, where R^3 is straight chain lower alkyl of 1-4 carbon atoms. R^1 is hydrogen, loweralkyl (C_1-C_6) or dialkylaminoalkyl (e.g., $-CH_2CH_2N(C_2H_5)_2$, $-CH_2CH(CH_3)N(CH_3)_2$.

An MDP-binding homing molecule having Structure 1 above can have an asymmetric form. Racemic Z-2-(2,2 dimethylcyclopropane carboxamido)-2-octenoic acid has been resolved. Activity resides in the dextrorotatory isomer, which has the S-configuration.

Within the definition of R^2 of a compound having Structure 1, the following sub-groups are included:

-R4

wherein R^4 is a straight, branched, or cyclic hydrocarbon radical of 3-10 carbon atoms which may be substituted as specified above in the definition of R^2;

$-R^5R^6$

wherein R^5 is cycloalkyl of 3-6 carbon atoms and R^6 is either 1 or 2 alkyl substituents which may be joined to form another ring on the cycloalkyl group, or R^5 and R^6 may be substituted as specified above in the definition of R^2; and

$-R^7R^8$

wherein R^7 is an alkylene group of 1-3 carbon atoms and R^8 is cycloalkyl of 3-6 carbon atoms which may be substituted as specified above in the definitions of R^2 and R^3.

Particularly preferred substituents within the definition of R^2 in Structure 1 include the 2,2-dimethylcyclopropyl and the 2,2-dichlorocyclopropyl groups.

Within the definition of R^3 in Structure 1, particularly preferred groups of compounds include n-alkyl (1-9 carbons) and n-alkyl (1-9 carbons) having a terminal substituent which is a quaternary nitrogen, amine derivative, or amino acid derived group.

The term "quaternary nitrogen" is used herein in reference to Structure 1 to mean a tetrasubstituted or heteroaromatic nitrogen which is positively charged. An ammonium moiety, substituted with hydrocarbon groups

having 1-7 carbon atoms, which can be the same or different, is signified.

As used herein in reference to Structure 1, the term "amino derivative" means a group such as amino, acylamino, ureido, amidino, guanidino and alkyl (1-7 carbon atoms) derivatives thereof.

As used herein in reference to Structure 1, the term "amino acid derived group" means a moiety such as cysteinyl ($-SCH_2CH(NH_2)COOH$) or sarcosyl ($-N(CH_3)CH_2COOH$) in which a hydrogen joined to O, N or S of known amino acids is replaced.

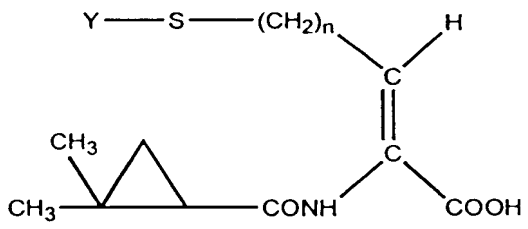
Particularly preferred MDP-binding homing molecules having Structure 1 are those in which R^2 is 2,2-dimethyl cyclopropyl or dichlorocyclopropyl, and R^3 is a hydrocarbon chain of 3 to 7 carbon atoms without a terminal substituent, or having a terminal substituent which is trimethylammonium, amidino, guanidino, or 2-amino-2-carboxyethylthio.

Exemplary MDP-binding homing molecules useful in the invention include Z-2-(2,2-dimethylcyclopropane carboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dichlorocyclopropane carboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dimethylcyclopropane carboxamido)-8-formamidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropane carboxamido)-8-ureido-2-octenoic acid; Z-8-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethyl cyclopropanecarboxamido)-2-octenoic acid; Z-2-(2,2-

dimethylcyclopropanecarboxamido)-2-octenoic acid (racemic and dextrorotatory forms); Z-2-(2,2-dichlorocyclopropanecarboxamido)-2-octenoic acid; 7-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid; and 6-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-hexenoic acid.

Methods for preparing an MDP-binding homing molecule having Structure 1 are disclosed herein and known in the art. Several methods for preparing such an MDP-binding homing molecule are set forth in Example VI (see, also, U.S. Patent No. 4,616,038 to Kahan et al., which is incorporated herein by reference).

Additional MDP-binding homing molecules known in the art also can be used to selectively target a gene or medication to lung endothelium according to a method of the invention. Such MDP-binding homing molecules include substituted 2-alkenoic acids including the following Structure 2:



wherein n is an integer from 3 to 5 and Y is a heterocyclic or phenyl group that may be substituted or unsubstituted, and the lower alkyl (C_1-$_6$) esters and pharmaceutically acceptable salts thereof.

As used herein in reference to Structure 2, the term "heterocyclic" means pyridyl, pyrimidinyl, tetrazolyl, imidazolyl, thiazolinyl and the like. Such heterocyclic rings and phenyl rings can be unsubstituted or substituted with hydroxyl, oxo, carbonyl, or methyl. Y-groups in Structure 2 include, for example, 2-pyridinyl; 4-pyridinyl; 3-hydroxy-2-pyridinyl; 3-carboxy-2-pyridinyl; 5-carboxy-2-pyridinyl; 2-carboxyphenyl; 1-methyl-1,2,3,4-tetrazol-5-yl; and 4-carboxy-6-hydroxy-2-pyrimidinyl.

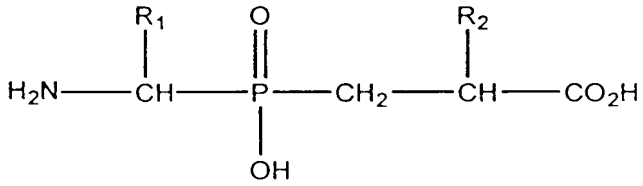
The configuration at the cyclopropyl center of a substituted 2-alkenoic acid MDP-binding homing molecule having Structure 2 preferably is S (+), although an R,S (+/-) racemic mixture of the compound also can be used in a method of the invention.

Particularly active MDP-binding homing molecules of this class are those in which n is 4 and Y is 3-carboxy-2-pyridyl or 3-hydroxy-2-pyridyl, each in the S-form. Exemplary MDP-binding homing molecules having Structure 2 include: Z-7-(3-hydroxy-2-pyridylthio)-2-(2,2-dimethylcyclopropane carboxyamido)-2-heptenoic acid and Z-(5-carboxy-2-pyridylthio)-2-(2,2-dimethylcyclopropanecarboxyamido)-2-heptenoic acid.

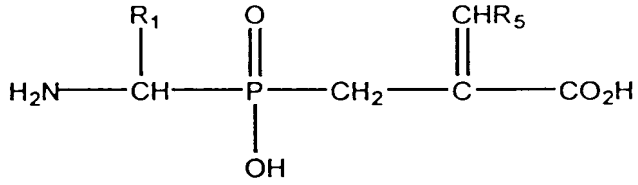
An MDP-binding homing molecule having Structure 2, as well as various pharmaceutically acceptable derivatives such as alkali and alkaline earth metal, ammonium or amine salts, or the like, which are also useful in the invention, can be prepared by the skilled person using routine methods. An

MDP-binding homing molecule having Structure 2 can be prepared, for example, by condensation of a bromoalkenoic acid with the appropriate mercaptan, YSH, in water in the presence of sodium bicarbonate at ambient temperature as described, for example, in U.S. Patent No. 4,406,902 to Ashton et al., which is incorporated herein by reference.

An MDP-binding homing molecule useful in the invention also can be a phosphinic acid having the following Structure 3:



or the following Structure 4:



where:

R_1 is

(a) C_2-C_{12} linear or branched unsubstituted alkyl;

(b) C_2-C_{12} linear or branched substituted alkyl;

(c) C_2-C_{12} linear or branched monoalkenyl;

(d) C_2-C_{12} linear or branched alkynyl;

(e) C_7-C_{20} aralkyl, wherein the alkyl chain is linear or branched C_1-C_8 and the aryl moiety is C_6-C_{12};

(f) C_3-C_7 cycloalkyl;

(g) C_4-C_{10} cycloalkylalkyl, for structure 4 only;

where the above values for R_1, excluding (a), can be substituted by one or more: C_1-C_4 alkoxy, C_6-C_{12} aryloxy, C_1-C_4 alkylthio, C_6-C_{12} arylthio, C_3-C_6 cycloalkyloxy, C_3-C_6 cycloalkylthio, C_7-C_{10} aralkyloxy, C_7-C_{16} aralkylthio;

R_2 is

(a) H or C_1-C_{12} linear or branched alkyl;

(b) C_2-C_{12} linear or branched monoalkenyl;

(c) C_7-C_{20} aralkyl, wherein the alkyl chain is linear or branched C_1-C_8 and the aryl moiety is C_6-C_{12};

(d) heterocyclic alkyl, wherein the alkyl chain is linear or branched C_1-C_8 and the heterocyclic ring is 5-6 membered, optionally fused with a benzene ring, fully aromatic, containing 1-2: 0, N or S heteroatoms;

(e) C_3-C_7 cycloalkyl;

(f) C_4-C_{10} cycloalkylalkyl;

where the above values for R_2 can be substituted by one or more: halo, hydroxy, carboxy, C_1-C_4 alkoxycarbonyl, C_7-C_{16} arylalkoxycarbonyl, C_3-C_7 cycloalkyl, C_1-C_4 alkoxy, C_6-C_{12} aryloxy, C_3-C_6 cycloalkyloxy, C_3-C_6 cycloalkylthio, amino, mono- or di-C_1-C_8 alkylamino, thio, C_1-C_4 alkylthio, C_6-C_{12} arylthio, C_7-C_{16} aralkylthio, or the radical $-S-(CH_2)_n-CH(NH_2)COOH$;

R^5 is

(a) H or C_1-C_{12} linear or branched alkyl;

(b) C_2-C_{12} linear or branched monoalkenyl;

(c) C_7-C_{20} aralkyl, wherein the alkyl chain is linear or branched C_1-C_8 and the aryl moiety is C_6-C_{12};

(d) heterocyclic alkyl, wherein the alkyl chain is linear or branched C_1-C_8 and the heterocyclic ring is 5-6 membered, optionally fused with a benzene ring, fully aromatic, containing 1-2: O, N or S heteroatoms;

(e) C_4-C_{10} cycloalkylalkyl;

(f) C_3-C_7 cycloalkyl;

where the above value for R_5 can be substituted by one or more: halo, hydroxy, carboxy, C_1-C_4 alkoxycarbonyl, C_7-C_{16} arylalkoxycarbonyl, C_3-C_7 cycloalkyl, C_1-C_4 alkoxy, C_6-C_{12} aryloxy, C_3-C_6 cycloalkyloxy, C_3-C_6 cycloalkylthio, amino, mono-or di-C_1-C_8 alkylamino, thio, C_1-C_4 alkylthio, C_6-C_{12} arylthio, C_7-C_{16} aralkylthio, or the radical $-S-(CH_2)_n-CH(NH_2)COOH$; and including MDP-binding stereoisomers and racemates thereof Structures 3 and 4.

In an MDP-binding homing molecule having Structure 3 or 4, the values for R_1 for (a) C_2-C_{12} linear or branched unsubstituted alkyl include ethyl, propyl, isopropyl, n-butyl, isobutyl, sec-butyl, t-butyl, n-pentyl, isopentyl, n-hexyl, n-heptyl, n-octyl, iso-octyl, n-decyl, n-undecyl, n-dodecyl and the like. Preferred in this series is n-butyl, isobutyl, n-pentyl and n-hexyl.

In an MDP-binding homing molecule having Structure 3 or 4, values for R_1 for (b) C_1-C_{12} linear or branched alkyl, where substituted, include the values above for R_1(a), substituted by the above-defined substituents, including the following preferred substituents: methoxy, ethoxy, propoxy, butoxy, methylthio, ethylthio, propylthio, butylthio, cyclopentyloxy, cyclopentylthio, cyclopropylthio,

benzylthio, 2-phenethylthio, 2-phenethylthio and the like.

In an MDP-binding homing molecule having Structure 3 or 4, values for R_1 for (e) C_2-C_2 linear or branched monoalkenyl include ethenyl, propenyl, 1-butenyl, 2-butenyl, 1-pentenyl, 2-pentenyl, 2-methyl-2-butenyl and the like.

In an MDP-binding homing molecule having Structure 3 or 4, values for R_1 for (d) C_2-C_{12} linear or branched alkynyl include: ethynyl, propynyl, 1-butynyl, 2-butynyl, 2-methyl-3-pentynyl and the like.

Values for R_1 for (d) C_2-C_{12} linear or branched alkynyl include: ethynyl, propynyl, 1-butynyl, 2-butynyl, 2-methyl-3-pentynyl and the like.

Values for R_1 for (e) C_7-C_{20} aralkyl include benzyl, 2-phenylethyl, 1-phenylethyl, 4-methylphenyl-methyl and the like. Preferred in this series is benzyl.

Values for R_1 for (f) C_4-C_{10} cycloalkylalkyl include: cyclohexylmethyl, cyclopentylmethyl, 2-cyclohexylethyl, 2-cycloctylethyl, and the like. Preferred in this series is cyclopentylmethyl and cyclohexylmethyl.

Values for R_1 for(g) C_3-C_7 cycloalkyl include: cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and the like. Preferred in this series is cyclopentyl and cyclohexyl.

Preferred substituent values for R_1 include: methoxy, ethoxy, phenoxy, methylthio, ethylthio, phenylthio, benzyloxy, 2-phenylethyloxy, benxylthio, 2-phenylethylthio, and the like.

The values of the alkyl, alkenyl groups for R_2 and R_5, except where noted otherwise, represented by any of the variables include linear or branched, alkyl and monoalkenyl and chain hydrocarbon radicals from two to twelve carbon atoms, for example, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, t-butyl, n-pentyl, isopentyl, n-heptyl, n-nonyl, 4,4-dimethylpentyl, or vinyl, allyl, 1-butenyl, 2-butenyl, 5-hexenyl and the like. Preferred are isopropyl, n-butyl, n-pentyl, n-heptyl or 1-butenyl.

Values of C_3-C_7 cycloalkyl and C_4-C_{10} cycloalkylalkyl include: cyclopentyl, cyclohexyl, cyclopentyl-methyl, cyclopentylethyl, cyclohexylmethyl, cyclohexylethyl, cyclopropyl, and the like.

The aralkyl group represented by the above variables has from one to eight carbon atoms in the alkyl portion and "aryl" where noted, represents phenyl, naphthyl, or biphenyl. Representative examples include benzyl, phenethyl, 4-phenyl-n-butyl, 1-phenyl-n-octyl, and the like.

In an MDP-binding homing molecule of the invention having Structure 3 or 4, the aromatic heterocyclic, i.e. "heteroaryl" substituent, are synonymous, and recited above represents a 5- or 6-membered aromatic ring containing from one to three O, N or S heteroatoms, preferably one O or S or 1-3N

heteroatoms, such as for example, pyridyl, thienyl, furyl, imidazolyl, and thiazolyl as well as any bicyclic group derivable therefrom in which any of the above heterocyclic rings is fused to a benzene ring such as, for example, indolyl, quinolinyl, isoquinolinyl, benzimidazolyl, benzothiazolyl, benzofuryl, and benzothienyl.

The named substituents on the R_2 and R_5 alkyl and alkenyl chains can be present on the aromatic rings in the aralkyl, heterocyclic alkyl and heteroaryl groupings as well. The site of substitution can be any available sites and the substitution can involve one or more of the same or different groups.

The substituents are: halo, meaning fluoro, chloro, bromo or iodo; hydroxy; carboxy; C_1-C_4 linear or branched alkoxycarboxy, e.g. methoxycarbonyl and ethoxycabonyl; C_7-C_{16} arylalkoxy carbonyl, e.g. benzyloxycarbonyl, n-butyloxyoarbonyl; C_3-C_7 cycloalkyl, e.g. cyclopentyl and cyclohexyl; C_1-C_4 alkoxy, e.g. t-butoxy and ethoxy; C_6-C_{12} aryloxy, e.g. biphenyloxy, benzyloxy; amino; mono- or di-C_1-C_8 dialkylamino, e.g. methylamino, isopropylamino, n-butylamino, isohexylamino, N,N-diethylamino, methylethylamino, methyl-t-butylamino, di-n-octylamino; thio; C_1-C_4 alkylthio, e.g. methylthio, ethylthio C_6-C_{12} arylthio, e.g. phenylthio; C_7-C_{16} aralkylthio, e.g. benzylthio, naphthyl-methylthio; the radicals -S-CH_2-$CH(NH_2)COOH$ and -S-$(CH_2)_2$-$CH(NH_2)COOH$, both preferably in the L-configuration; and, where a thio substituent is present, R_2 or R_5 must be at least a C_2 alkyl grouping. Where an aryl or heteroaryl group is present in the substituent, the ring carbons can additionally

be substituted by one or more of linear or branched C_1-C_4 alkyl, e.g. methyl, ethyl, isopropyl, t-butyl; trihalomethyl, "halo" having the same meaning as described above, e.g. trichloromethyl, trifluoromethyl; nitro, cyano or sulfonamide.

Preferred are the compounds wherein: R_1 is cyclohexylmethyl, cyclopentyhnethyl, n-pentyl, n-butyl, n-hexyl, isobutyl, R_2 and R_5 are: C_3-C_7 cycloalkyl; C_1-C_{10} linear or branched alkyl, substituted or unsubstituted; C_7-C_{14} aralkyl, substituted or unsubstituted. Wherein these groups can be substituted with halo, amino, mono- or di-C_1-C_4 linear or branched alkylamino, carboxyl, C_1-C_4 alkoxycarbonyl, hydroxy, C_1-C_4 alkoxy, C_5-C_6 cycloalkyl, C_6-C_{10} aryroxy, thio, C_1-C_4 linear or branched alkylthio, C_6-C_{10} arylthio, C_7-C_{14} aralkylthio, $-S-(CH_2-)_n-CH(NH_2)CO_2H$; wherein the aryl group ring carbons can further be substituted by linear or branched C_1-C_4 alkyl; R_3 and R_4 are hydrogen, C_1-C_4 linear or branched alkyl e.g. methyl, ethyl, or C_7-C_{14} aralkyl e.g. benzyl.

In an MDP-binding homing molecule having Structure 3 or 4, the carbon preferably is attached to R_1 in the (R) or (RS) configuration, more preferably (R), and the carbon attached to R_2 is in the (R), (RS) or (S) configuration, preferably (RS) or (S) and if R_5 is present, the double bond preferably is in the Z configuration. One skilled in the art understands that an MDP-binding homing molecule based on Structure 3 can be used in the form of salts derived from inorganic or organic acids and bases.

Methods for preparing an MDP-binding homing molecule having Structure 3 or Structure 4 are well known in the art. See, for example, Parsons et al., Biochemistry International 23:1107-1115 (1991); and U.S. Patent No. 5,145,990, each of which is incorporated herein by reference.

A variety of other MDP-binding homing molecules known in the art also can be useful for selectively directing a gene or medication to lung endothelium according to a method of the invention. Such MDP-binding homing molecules include those described in Kahan et al., U.S. Patent No. 4,616,038; Ashton et al., U.S. Patent No. 4,406,902; Parsons et al., U.S. Patent No. 5,145,990; Parsons et al., Biochem. International 23:1107-1115 (1991); Uchida et al., U.S. Patent No. 5,061,730; Hashimoto et al., J. Antibiotics XLIII:281-285 (1990); and Takase et al., J. Antibiotics XLIII:38-42 (1990), each of which is incorporated herein by reference.

Metastatic cells display an altered repertoire of cell adhesion molecules, allowing escape from the primary tumor, adhesion and penetration of the extracellular matrix and entry into the microvasculature. Most such cells are destroyed by geometric and hemodynamic forces in their first encounter with the narrow capillary net, usually in the lungs. Although the frequency of metastasis to the lungs has been attributed solely to mechanical entrapment of tumor cell emboli, it has long been observed that certain tumor cell types prefer to metastasize to specific target organs.

Several lines of evidence indicate that the selection of a target organ for metastasis is mediated by specific interactions between blood-born cancer cells and the endothelium of that target organ (Albelda, Lab. Invest. 68: 4-17 (1993); Auerbach et al., Cancer Res. 47:1492-1496 (1987); Johnson et al., Cancer Res. 51:394-399 (1991), each of which is incorporated herein by reference). In the lung, two vascular receptors have been found to mediate adhesion of metastatic cells. LuECAM-1, an endothelial surface protein with sequence homology to chloride channels, mediates adhesion of malignant melanoma cells to lung endothelium (Elble et al., J. Biol. Chem. 272:27853-27861 (1997), which is incorporated herein by reference). Furthermore, a protease, lung endothelial dipeptidylpeptidase IV (DPP IV/CD 26), promotes homing of metastatic breast and prostate carcinoma cells to lung (Johnson et al., J. Cell Biol. 121: 1423-1432 (1993), which is incorporated herein by reference). Fibronectin present on the surface of the metastatic cells was shown to be the ligand for DPP IV-dependent homing of the breast cancer cells to lung vasculature (Chen et al., J. Biol. Chem. 273:24207-24215 (1998), which is incorporated herein by reference). These results indicate that organ-selective homing can be mediated by classical cell adhesion molecules as well as other molecules.

As disclosed herein, selective homing of GFE-1 (SEQ ID NO: 1) to lung endothelium *in vivo* is mediated by the cell surface protease, MDP. As further disclosed herein, administration of GFE-1 (SEQ ID NO: 1) can inhibit experimental lung metastasis of two melanoma cell lines (human C8161 and mouse B16) in

mice, demonstrating that GFE-1 (SEQ ID NO; 1) can compete with metastasizing tumor cells for binding to the same receptor (see Figure 8). These results indicate that MDP serves as a receptor for metastasizing tumor cells on lung vasculature and that an MDP-binding homing molecule can reduce or prevent the anchoring of lung metastases.

Thus, the present invention provides a method of reducing or preventing lung metastasis in a subject having cancer by administering to the subject a membrane dipeptidase (MDP)-binding homing molecule. Primary tumors that commonly spread to the lungs include breast, colorectal, lung, testicular, pancreatic, esophageal, stomach, ovarian, renal cell and prostate carcinomas, osteogenic and soft tissue sarcomas and melanoma (Smith, Seminars Oncology Nurs. 14:178-186 (1998), which is incorporated herein by reference). The methods of the invention can be used, for example, to reduce or prevent lung metastasis of breast cancer, kidney cancer, melanoma, bladder cancer, cancer of the cervix, ovarian cancer, prostate cancer, colorectal cancer or lung cancer.

As used herein, the term "metastasis" means the transfer of malignant cells from one site to another site not directly connected with it, after which the cells form a proliferative focus. Thus, metastatic cells become detached from a primary tumor, move to a different part of the body and grow as a separate mass of tumor. One skilled in the art understands that a malignant cell can travel locally from a first site within an organ to a second site within the same organ or can travel distantly within

the body to a different organ. Furthermore, malignant cells of a metastasis can themselves give rise to additional metastases.

The term "lung metastasis," as used herein, refers to the transfer of malignant cells to one or more sites within lung not directly connected with the first site, after which the cells form a proliferative focus within the lung. The resulting detached masses of cancer cells within the lung are termed lung "metastases" or secondary tumors. Lung metastases can originate from a variety of primary cancers, which they generally will resemble histologically. Breast cancer, kidney cancer and melanoma, for example, frequently metastasize to lung. In addition, cancers of the bladder, cervix, ovary and prostate metastasize to lung and, less frequently, colorectal cancers or primary lung cancers metastasize to one or more secondary sites in lung.

The term "reducing or preventing," as used herein in reference to lung metastasis, means that the rate or extent of lung metastasis is diminished. Thus, lung metastasis is reduced or prevented where the development of lung metastasis is completely precluded or is significantly delayed; or where the size or number of lung metastases is significantly diminished. One skilled in the art understands that a delay in development of lung metastases or a decrease in the size or number of lung metastases is measured relative to the rate or extent of lung metastases in one or more control subjects not treated with an MDP-binding homing molecule according to a method of the invention.

If addition, a subject not having detectable cancer can be treated prophylactically with an MDP-binding homing molecule to reduce or prevent the future occurrence of lung metastases. Such a subject can be, for example, suspected of having cancer or can have a family history of cancer.

As set forth above, an MDP-binding homing molecule exhibits selective homing to lung endothelium and is characterized, in part, by exhibiting specific binding to membrane dipeptidase. An MDP-binding homing molecule useful in reducing or preventing lung metastasis can readily be identified by specific binding to MDP as described hereinabove. If desired, additional MDP-binding homing molecule also can be identified by the ability to competitively inhibit binding of known MDP-binding peptides, for example, GFE-1 (SEQ ID NO: 1) or cells, for example, C8161 cells to membrane dipeptidase.

In one embodiment, an MDP-binding homing molecule useful in reducing or preventing lung metastasis is a lung homing peptide including the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids, such as a peptide including the sequence CGFECVRQCPERC (SEQ ID NO: 1) or CGFELETC (SEQ ID NO: 2). Such an MDP-binding homing molecule can be, for example, the peptide CGFECVRQCPERC (SEQ ID NO: 1) or CGFELETC (SEQ ID NO: 2). Additional MDP-binding homing molecules containing the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids, can be identified as described below, for

example, by screening a combinatorial peptide library which includes the motif GFE as invariant residues.

In another embodiment, an MDP-binding homing molecule is a membrane dipeptidase inhibitor. As used herein, the term "membrane dipeptidase inhibitor" is synonymous with "MDP inhibitor" and means an organic molecule that selectively decreases the enzymatic activity of membrane dipeptidase. In general, an MDP inhibitor is a molecule that binds to the active site of MDP. An MDP inhibitor can be an organic molecule such as a drug; peptide; modified peptide or peptide mimetic; protein or protein fragment; nucleic acid molecule such as a ribonucleic or deoxyribonucleic acid; oligosaccharide; lipid; glycolipid; or lipoprotein. Exemplary MDP inhibitors disclosed herein are CGFECVRQCPERC (SEQ ID NO: 1) and cilastatin.

The term "selectively inhibits," as used herein in reference to an MDP inhibitor, means that the inhibitor decreases MDP activity in a manner that is selective for the MDP enzyme as compared to related but different enzymes such as other proteases. Thus, an MDP inhibitor is distinct from a non-specific inhibitor of, for example, zinc metalloproteases. Thus, an MDP inhibitor can selectively decrease MDP activity while having little or no effect on the activity of, for example, dipeptidyl peptidase IV.

Assays for measuring MDP enzymatic activity are known in the art. MDP cleaves dipeptide substrates in which the N-terminal amino acid is in the L-configuration and is unblocked. The C-terminal amino acid is either in the L- or D-configuration, with the

enzyme hydrolyzing substrates with a D-configuration C-terminal residue more rapidly. MDP activity can be assayed, for example, using glycyl-D-phenylalanine (Gly-D-Phe) as a substrate (Keynan et al., *supra*, 1996; Parsons et al., *supra*, 1991). A convenient specific fluorimetric assay for MDP enzymatic activity uses Gly-D-Phe as a substrate and subsequent reaction of D-amino acid oxidase with the released D-Phe (see Example IVE; see, also, Heywood and Hooper, Analyt. Biochem. 226:10-14 (1995), which is incorporated herein by reference).

A membrane dipeptidase inhibitor can be a molecule that exhibits structural homology to a natural MDP substrate. For example, following cleavage of the tripeptide glutathione by γ-glutamyl transpeptidase to form glutamate and cysteinylglycine (Cys-Gly), the dipeptide Cys-Gly is recognized and cleaved by MDP, which cleaves only dipeptides. The amino acid sequence of glutathione is similar to the N-terminal portion of GFE-1 (SEQ ID NO: 1), in which the first two amino acids are Cys-Gly. As shown in Figure 7, GFE-1 (SEQ ID NO: 1) inhibits hydrolysis of the Gly-D-Phe substrate in a dose-dependent manner, indicating that GFE containing peptides such as GFE-1 (SEQ ID NO: 1) can be MDP inhibitors. These results further indicate that an MDP inhibitor can be structurally similar to a naturally occurring MDP substrate.

A variety of MDP inhibitors are known in the art. For example, an MDP inhibitor can be an MDP-binding homing molecule such as an MDP-binding molecule having Structure 1, Structure 2, Structure 3 or Structure 4, described hereinabove.

An MDP inhibitor useful in the invention can have, for example, a Ki for membrane dipeptidase of about 10^{-4} M to about 10^{-12} M. For example, a MDP inhibitor including the sequence X_1-G-F-E-X_2 (SEQ ID NO: 17), where X_1 and X_2 each is 1 to 10 independently selected amino acids, can have, for example, a Ki for membrane dipeptidase of about 2 x 10^{-5} M to 10^{-7} M, for example, a Ki of about 10^{-6} to 10^{-7} M.

An MDP inhibitor useful in the invention can exhibit, for example, a Ki against MDP of 1000 nM or less. An MDP inhibitor useful in reducing or preventing lung metastasis also can exhibit, for example, a Ki against MDP of 100 nM or less or a Ki of 1 nM or less. For example, an MDP inhibitor having Structure 3 or Structure 4 can be a tight binding inhibitor with a Ki from, for example, about 0.5 nM to 10 nM. MDP inhibitors having Structure 3 or Structure 4 therefore can be particularly useful in the methods of the invention for reducing or preventing lung metastasis by administering an MDP inhibitor to a subject having cancer.

In another preferred embodiment, an MDP inhibitor comprises Structure 1, where R^2 and R^3 are hydrocarbon radicals in the range respectively of 3-10 and 1-15 carbon atoms; in either one of these R^2 or R^3 hydrocarbon chains 1-6 hydrogens may be replaced by halogens or a nonterminal methylene may be replaced by oxygen or sulfur, including oxidized forms of the latter; additionally, a terminal hydrogen in R^3 can also be replaced by hydroxyl or thiol, which may be acylated or carbamoylated; or the hydrogen can be replaced by amino, which may be derivatized as in an

acylamino, ureido, amidino, quanidino, or alkyl or substituted amino group, including quaternary nitrogen grouping; or, there may be replacement by acid groups such as carboxylic, phosphonic or sulfonic acid groups or esters or amides thereof, or cyano; or combinations thereof, such as a terminal amino acid grouping; and R^1 is hydrogen or lower alkyl (C_{1-6}) or dialkylaminoalkyl, or a pharmaceutically acceptable cation. Such an MDP inhibitor for reducing or preventing lung metastasis can be, for example, 7-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid, also known as cilastatin.

An MDP inhibitor can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl with a limitation that the carbon adjacent to the carbonyl cannot be tertiary.

An MDP inhibitor also can be, for example, a compound having Structure 1 in which R^2 is branched alkyl or cycloalkyl with a limitation that the carbon adjacent to the carbonyl cannot be tertiary, and in which R^3 is n-alkyl (1-9 carbons) or n-alkyl (1-9 carbons) having a terminal substituent which is a quaternary nitrogen, amine derivative or amino acid derived group. An MDP inhibitor can be, for example, a compound having Structure 1 in which R^2 is 2,2-dimethylcyclopropyl or 2,2-dichlorocyclopropyl and in which R^3 is a hydrocarbon chain of 3 to 7 carbon atoms without a terminal substituent or having a terminal substituent which is trimethylammonium, amidino, guanidino or 2-amino-2-carboethylthio.

Exemplary MDP inhibitors having Structure 1 useful in the invention include the following: Z-2-(2,2-dimethylcyclopropane carboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dichlorocyclopropanecarboxamido)-8-trimethylammonium hydroxide-2-octenoic acid inner salt; Z-2-(2,2-dimethylcyclopropane carboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-guanidino-2-octenoic acid; Z-2-(2,2-dimethylcyclopropanecarboxamido)-8-ureido-2-octenoic acid; Z-8-(1-2-amino-2-carboxy ethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-octenoic acid; Z-2-(2,2-dimethylcyclopropane carboxamido)-2-octenoic acid (racemic and dextrorotatory forms); Z-2-(2,2-dichloro cyclopropanecarboxamido)-2-octenoic acid;7-(L-2-amino-2-carboxyethylthio) -2-(2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid; and 6-(L-2-amino-2-carboxyethylthio)-2-(2,2-dimethylcyclopropane carboxamido)-2-hexenoic acid.

The present invention also provides a method of reducing or preventing lung metastasis in a subject having cancer by administering to the subject a MDP negative regulatory agent. A MDP negative regulatory agent useful in the invention can be, for example, a soluble MDP polypeptide or an antibody that selectively reacts with MDP.

Further provided herein are methods of reducing or preventing cell homing to lung endothelium in a subject by administering to the subject a MDP negative regulatory agent. A MDP negative regulatory agent useful for reducing or preventing cell homing to

lung endothelium can be, for example, a soluble MDP polypeptide or an antibody that selectively reacts with MDP.

As used herein, the term "MDP negative regulatory agent" means an organic molecule that, directly or indirectly, selectively reduces MDP expression or activity. Such MDP negative regulatory agents can be, for example, drugs; nucleic acid molecules, including ribonucleic acid molecules and deoxyribonucleic acid molecules; peptides; variants or modified peptides or peptide mimetics; proteins or fragments thereof; antibodies or fragments thereof; oligosaccharides; lipids; glycolipids; or lipoproteins.

One skilled in the art understands that a MDP negative regulatory agent can act by a variety of mechanisms to selectively reduce MDP expression or activity. An MDP negative regulatory agent can be, for example, an organic molecule that acts to reduce the amount of functional MDP expressed in lung endothelium. Such an agent can selectively reduce MDP transcription or translation and can be, for example, an antisense oligonucleotide, a transcription factor that negatively regulates MDP expression, or a nucleic acid molecule encoding such a transcription factor.

An MDP negative regulatory agent also can be, for example, a fragment of MDP that effectively competes with wild type membrane dipeptidase to reduce or prevent metastatic or other cells from selectively homing to MDP in lung endothelium. A soluble, extracellularly expressed form of MDP or other dominant negative fragment of MDP can be a MDP negative

regulatory agent useful in the invention. A MDP regulatory agent also can be an MDP mimic, which is a protein or other organic molecule that shares tertiary structural homology with MDP or a subpart thereof, and which, when expressed, competes with endogenous MDP for binding to metastatic or other homing cells such as lymphocytes. An MDP mimic can structurally resemble the region of MDP that contacts a metastatic cell; an MDP mimic can structurally resemble, for example, the active site of MDP.

In one embodiment, a MDP negative regulatory agent is an antibody that selectively reacts with MDP. As used herein, an antibody that "selectively reacts with MDP" binds with substantially higher affinity to membrane dipeptidase than to an unrelated polypeptide such as another zinc metalloprotease. The term "antibody" is used herein in its broadest sense to include polyclonal and monoclonal antibodies, as well as polypeptide fragments of antibodies that retain a selective affinity for membrane dipeptidase of at least about $1 \times 10^5\ M^{-1}$. Antibody fragments such as Fab, $F(ab')_2$ and Fv fragments can selectively react with membrane dipeptidase and, therefore, are included within the meaning of the term antibody as defined herein. The term antibody as used herein includes naturally occurring antibodies, as well as non-naturally occurring antibodies and fragments such as chimeric antibodies and humanized antibodies that are selectively reactive with membrane dipeptidase.

Methods for producing antibodies are routine in the art. Membrane dipeptidase, which can be prepared from natural sources or produced recombinantly

as described above, or a fragment thereof, such as a synthetic peptide, can be used as an immunogen. Non-immunogenic fragments or synthetic peptides can be made immunogenic by coupling the hapten to a carrier molecule such as bovine serum albumin (BSA) or keyhole limpet hemocyanin (KLH). In addition, various other carrier molecules and methods for coupling a hapten to a carrier molecule are well known in the art as described, for example, by Harlow and Lane, Antibodies: A Laboratory Manual (Cold Spring Harbor Laboratory Press, 1988), which is incorporated herein by reference. Antibodies, including non-naturally occurring antibodies such as, chimeric and humanized antibodies, also can be constructed using solid phase peptide synthesis, produced recombinantly or obtained, for example, by screening combinatorial libraries consisting of variable heavy chains and variable light chains as described by Borrebaeck (Ed.), Antibody Engineering (Second edition) New York: Oxford University Press (1995), which is incorporated herein by reference.

In another embodiment, a MDP negative regulatory agent is a soluble MDP polypeptide. As used herein, the term "soluble polypeptide" means a polypeptide that is not membrane bound. A soluble MDP polypeptide useful in the invention is secreted and, thus, expressed extracellularly.

A soluble MDP polypeptide useful in the invention can be, for example, a truncated or mutated MDP polypeptide lacking one or more C-terminal residues required for GPI anchor addition (see Figure 9). To determine whether a particular truncated or mutated MDP

derivative is soluble, the derivative can be expressed, for example, in COS cells, and the transfected cells and supernatant subsequently assayed for MDP activity to determine whether the MDP is membrane bound or soluble.

The present invention also provides a method of identifying a molecule that reduces or prevents lung metastasis by contacting membrane dipeptidase (MDP) with one or more molecules; and determining MDP activity in the presence of the molecule as compared to a control value, where diminished MDP activity in the presence of the molecule identifies the molecule as a molecule that reduces or prevents lung metastasis. The membrane dipeptidase can be, for example, substantially purified. MDP activity can be determined, for example, by release of D-Phe from Gly-D-Phe.

In one embodiment of the invention, a molecule that reduces or prevents lung metastasis can be identified by contacting membrane dipeptidase (MDP) with one or more molecules; determining MDP activity in the presence of the molecule as compared to a control value; administering the molecule to a subject having cancer; and assaying lung metastasis in the subject as compared to a control level of metastasis, where diminished MDP activity in the presence of the molecule identifies the molecule as a molecule that reduces or prevents lung metastasis.

The following examples are intended to illustrate but not limit the present invention.

EXAMPLE I

***IN VIVO* PANNING**

This example demonstrates methods for preparing a phage display library and screening the library using *in vivo* panning to identify phage expressing peptides that home to a selected organ or tissue.

A. Preparation of phage libraries:

Phage display libraries were constructed using the fuse 5 vector as described by Koivunen et al., *supra*, 1995; see, also, Koivunen et al., *supra*, 1994b). Libraries encoding peptides designated CX_6C (SEQ ID NO: 26), CX_7C (SEQ ID NO: 24), $CX_{10}C$ (SEQ ID NO: 30)) $CX_3CX_3CX_3C$ (SEQ ID NO: 25), X_2CX_4CX (SEQ ID NO: 23), and X_7 (SEQ ID NO: 29), were prepared, where "C" indicates cysteine and "X_N" indicates the given number of individually selected amino acids. These libraries can display cyclic peptides when at least two cysteine residues are present in the peptide.

The libraries containing the defined cysteine residues were generated using oligonucleotides constructed such that "C" was encoded by the codon TGT and "X_N" was encoded by NNK, where "N" is equal molar mixtures of A, C, G and T, and where "K" is equal molar mixtures of G and T. Thus, the peptide represented by CX_6C (SEQ ID NO: 26) can be represented by an oligonucleotide having the sequence $TGT(NNK)_6TGT$ (SEQ ID NO: 31). Oligonucleotides were made double stranded by 3 cycles of PCR amplification, purified and ligated to the nucleic acid encoding the gene III protein in

the fuse 5 vector such that, upon expression, the peptide is present as a fusion protein at the N-terminus of the gene III protein.

The vectors were transfected by electroporation into MC1061 cells. Bacteria were cultured for 24 hr in the presence of 20 µg/ml tetracycline, then phage were collected from the supernatant by precipitation twice using polyethylene glycol. Each library contained about 10^{12} transducing units/ml (TU; individual recombinant phage).

B. *In vivo* panning of phage:

For lung and pancreas, a mixture of phage libraries containing 10^{10} TU was diluted in 200 µl DMEM and injected into the tail vein of anesthetized BALB/c mice (2 month old; Harlan Sprague Dawley; San Diego CA); AVERTIN (0.017 ml/g) was used as anesthetic (Pasqualini and Ruoslahti, *supra*, 1996). After 1-4 minutes, mice were snap frozen in liquid nitrogen or, after about 5 minutes of phage circulation, the mice were perfused through the heart with 5-10 ml of DMEM (SIGMA; St. Louis MO). To recover the phage, the organs from the perfused mice or partially thawed organs from snap frozen mice were collected and weighed, then were homogenized in 1 ml DMEM-PI (DMEM containing protease inhibitors (PI); phenylmethyl sulfonyl fluoride (PMSF; 1 mM), aprotinin (20 µg/ml), leupeptin (1 µg/ml)).

Organ samples were washed 3 times with ice cold DMEM-PI containing 1% bovine serum albumin (BSA), then directly incubated with 1 ml K91-kan bacteria for

1 hr. Ten ml NZY medium containing 0.2 µg/ml tetracycline (NZY/tet) was added to the bacterial culture, the mixture was incubated in a 37°C shaker for 1 hr, then 200 µl aliquots were plated in agar plates containing 40 µg/ml tetracycline (tet/agar).

For *in vivo* panning of skin, two month old BALB/c nude mice were used to avoid contamination by hair. The mice were injected intravenously with phage as described above and, after perfusion through the heart, the skin was removed in large sections and placed on an ice cold plate with the hypodermis facing up. The skin was scraped with a scalpel to remove mostly hypodermis, which was then processed for phage recovery as described below.

For *in vivo* panning of retina, two month old female Simonson Albino rats were used to provide larger tissue samples than mice. The rats were anesthetized with phenobarbital (50 mg/kg body weight), and, while under deep anesthesia, the abdominal cavity of the rats was opened and 10^{10} TU of a phage library was injected into the left ventricle of the heart through the diaphragm. After 2-5 minutes of phage circulation, the eyes were removed, then washed once in 70% EtOH and once in PBS. The anterior chamber, with cornea and lens, was removed and the retina was peeled from the remaining posterior chamber. The tissue was weighed, homogenized with a syringe bulb in 1 ml of ice cold DMEM containing protease inhibitors (1 mM PMSF, 20 µg/ml aprotinin and 1 µg/ml of leupeptin; all from SIGMA; St. Louis MO). The tissue was washed 3 times with 1 ml of DMEM and the phage were rescued as described below.

Approximately 250 to 300 individual bacterial colonies containing phage recovered from the various organs or tissues were grown for 16 hr in 5 ml NZY/tet. In some experiments, approximately 1000 individual bacteria containing phage were picked and the phage were amplified in 2 ml of NZY/tet or the entire plate containing phage was scraped, pooled and grown in bulk and processed for injection. Where phage were cultured separately, the cultures were pooled and the phage were injected into mice or rats as described above for a second round of *in vivo* panning. In some experiments, a third or fourth round of panning was performed. Phage DNA was purified from individual bacterial colonies obtained and the DNA sequences encoding the peptides expressed by selected phage were determined (see Koivunen et al., *supra*, 1994b).

EXAMPLE II

CHARACTERIZATION OF PEPTIDES THAT HOME TO A SELECTED ORGAN

This example demonstrates that an organ or tissue homing peptide of the invention selectively homes to a selected organ or tissue including an organ containing a component of the RES.

A. Lung is the selected organ

After two or three rounds of *in vivo* panning of mice injected with a cyclic $CX_3CX_3CX_3C$ (SEQ ID NO: 25) or a cyclic CX_6C (SEQ ID NO: 26) phage display library, four peptides that homed to lung were identified. The peptide sequences CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) and CGFELETC (SEQ ID NO: 2; GFE-2)

appeared repeatedly in the lung and two peptide sequences from the CX_6C (SEQ ID NO: 26) library CTLRDRNC (SEQ ID NO: 15) and CIGEVEVC (SEQ ID NO: 16) also were found to home to lung (see Table 2, below).

To determine the specificity of lung homing of the individual peptides identified, phage displaying the peptides were amplified individually, diluted to the same input titer and administered to mice. Following administration, control kidney and brain organ was removed and the number of TU of phage in lung, kidney and brain was determined. The results shown in Figure 2 reveal that 10x and 35x more phage having the peptide sequence CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) bound to lung than to kidney and brain, respectively. Figure 2 also reveals that CGFELETC (SEQ ID NO: 2; GFE-2) was found in lung at a 12x and 20x greater level than in kidney and brain, respectively. The lung homing peptides CGFECVRQCPERC (SEQ ID NO: 1; GFE-1), CGFELETC (SEQ ID NO: 2; GFE-2), CTLRDRNC (SEQ ID NO: 15) and CIGEVEVC (SEQ ID NO: 16) are enriched in lung at 35x, 9x, 6x and 5x, respectively, over unselected phage (see Figure 2). Thus, substantial enrichment of phage binding to the lung was observed in comparison to control brain and kidney and in comparison to unselected phage.

Specificity for the lung homing peptides was also determined by competition experiments with GST-fusion peptides. A GST-GFE-1 (SEQ ID NO: 1) fusion peptide coadministered with GFE-1 (SEQ ID NO: 1) inhibited GFE-1 (SEQ ID NO: 1) homing to the lung, whereas GST had no effect on homing (Figure 3A). In addition, the inhibitory effect of the GST-GFE-1 (SEQ

ID NO: 1) on homing was dose dependent; 70% inhibition of homing occurred when injecting 500 µg of the GST-GFE-1 (SEQ ID NO: 1) fusion protein (Figure 3B). Coinjection of GST-GFE-2 (SEQ ID NO: 2) with GFE-2 (SEQ ID NO: 2) inhibited homing to a lesser extent; 30% inhibition of homing occurred when injecting 500 µg of the GST-GFE-2 (SEQ ID NO: 2) fusion protein (Figure 3B). Interestingly, the GST-GFE-1 (SEQ ID NO: 1) fusion was more efficient at inhibiting GFE-2 (SEQ ID NO: 2) homing to the lung; 60% inhibition of GFE-2 (SEQ ID NO: 2) homing occurred when injecting 500 µg of the GST-GFE-1 (SEQ ID NO: 1) fusion protein (Figure 3B). However, no inhibitory effect of GFE-1 (SEQ ID NO: 1) homing was observed when coinjecting GST-GFE-2 (SEQ ID NO: 2). This can be explained by GFE-1 (SEQ ID NO: 1) having a higher affinity for a shared target molecule than GFE-2 (SEQ ID NO: 2).

Additional lung homing peptides were obtained and the amino acid sequences were determined for the inserts (see Table 2). Peptides containing a GFE motif predominated (see Table 1; SEQ ID NOS: 1 and 2). Other peptides that were present more than once in lung are indicated by an asterisk in Table 2 (below), and the remaining peptides were identified one time each.

These results indicate that the selection of the peptides containing the GFE motif represents the selective binding of several independent phage displaying peptides having the GFE sequence and is not an artifact due, for example, to phage amplification. In addition, in some cases, phage that expressed peptides having the same amino acid sequence were encoded by oligonucleotides having different sequences,

therefore confirming that homing of a particular phage to a lung is due to the specific peptide expressed on the phage.

These results demonstrate that *in vivo* panning can be used to screen phage display libraries in order to identify phage expressing peptides that home to lung, which contain a component of the RES.

B. Skin is the selected tissue:

After two or three rounds of *in vivo* panning of mice injected with a cyclic $CX_3CX_3CX_3C$ (SEQ ID NO: 25) phage display library, the peptide sequence CVALCREACGEGC (SEQ ID NO: 3), which appeared repeatedly in skin, was identified (Table 1). To determine the specificity of skin homing of the sequence CVALCREACGEGC (SEQ ID NO: 3), phage displaying the peptide was amplified individually, diluted to the same input titer and administered to mice. Following administration, control kidney and brain organ were removed and the number of TU of phage in skin, kidney and brain was determined.

The results revealed that 7x more phage displaying the peptide sequence CVALCREACGEGC (SEQ ID NO: 3) bound to skin than to kidney or brain (see Figure 2; Table 1). The peptide CVALCREACGEGC (SEQ ID NO: 3) was enriched in skin 7x over unselected phage (Figure 2). Thus, substantial enrichment of phage binding to the skin was observed in comparison to control brain and kidney and in comparison to unselected phage.

Additional skin homing peptides were obtained by screening the cyclic $CX_3CX_3CX_3C$ (SEQ ID NO: 25) or $CX_{10}C$ (SEQ ID NO: 30) phage display libraries; amino acid sequences were determined for the inserts as shown in Table 5, below. Peptides that were identified more than one time during screening are indicated by an asterisk. For example, 14% of recovered $CX_3CX_3CX_3C$ (SEQ ID NO: 25) phage that homed to head skin had the sequence CVDVCCDGCPVCC (SEQ ID NO: 437). Phage having the sequence RVPLSGDVEH (SEQ ID NO: 438), LRVMSFTSGQ (SEQ ID NO: 439), or RFSVGSLFGS (SEQ ID NO: 440) each constituted 14% of recovered $CX_{10}C$ (SEQ ID NO: 30) phage that homed to head skin. Screening against homing to tail skin revealed that 12% of recovered $CX_3CX_3CX_3C$ (SEQ ID NO: 25) phage had the sequence CGATCEMQCPSGC (SEQ ID NO: 441).

Specificity for the skin homing peptides was also determined by competition experiments with GST-fusion peptides. Figure 3B shows that a GST-CVALCREACGEGC (SEQ ID NO: 3) fusion peptide coadministered with CVALCREACGEGC (SEQ ID NO: 3) inhibited homing to the skin, whereas GST had no effect on homing. The inhibitory effect of the GST-GFE-1 on homing was about 55% when injecting 500 µg of the GST-CVALCREACGEGC (SEQ ID NO: 3) fusion protein (Figure 3B).

These results demonstrate that *in vivo* panning can be used to screen phage display libraries in order to identify phage expressing peptides that home to skin and that such homing is specific.

C. Pancreas is the selected organ:

After two or three rounds of *in vivo* panning of mice injected with a cyclic CX_7C (SEQ ID NO: 24) phage display library, various pancreas homing peptides were identified (Table 3). In particular, the peptide sequence SWCEPGWCR (SEQ ID NO: 4) appeared repeatedly in the pancreas. To determine the specificity of SWCEPGWCR (SEQ ID NO: 4), a phage displaying the sequence was amplified individually, diluted to the same input titer and administered to mice. Following administration, control brain organ was removed and the number of TU of phage in each pancreas and was determined. The results shown in Figure 2, reveal that 10x more phage displaying the peptide sequence SWCEPGWCR (SEQ ID NO: 4) bound to pancreas than to brain and additional experiments revealed up to 20x enrichment in pancreas as compared to brain (Table 1). In addition, SWCEPGWCR (SEQ ID NO: 4) exhibited a 22x enrichment of phage to the pancreas as compared to unselected phage (see Figure 2). Thus, substantial enrichment of phage binding to the pancreas was observed in comparison to control tissue (brain) and to unselected phage.

These results demonstrate that *in vivo* panning can be used to identify molecules that selectively home to pancreas. In addition, the results indicate that *in vivo* panning identifies independent phage encoding the same peptide.

D. Retina is the selected tissue

Rats injected with a cyclic CX_7C (SEQ ID NO: 24) phage display library were subjected to *in vivo* panning and, after three rounds, the peptide sequences CSCFRDVCC (SEQ ID NO: 5) and CRDVVSVIC (SEQ ID NO: 6) were identified in retina. Because of small tissue sample size, the phage isolated could not be accurately quantitated. Thus, the selectivity of phage displaying the peptides was determined by individually amplifying the phage displaying the sequence and administering the phage to rats with a control phage fdAMPLAY88. This fd-ampicillin phage is similar to fd-tetracycline (fuse 5-based) in that it has the same infectivity.

Rats were injected with an equal amount of the CSCFRDVCC (SEQ ID NO: 5) or CRDVVSVIC (SEQ ID NO: 6) and the fdAMPLAY88 phage. Following administration, homing to retina was evaluated by comparing the number of TU of the selected phage on tetracycline plates and fdAMPLAY88 on ampicillin plates recovered from retina.

The results revealed that CSCFRDVCC (SEQ ID NO: 5) showed a 3x enrichment and CRDVVSVIC (SEQ ID NO: 6) showed a 2x enrichment in retina compared to control fdAMPLAY88 phage. Thus, substantial enrichment of phage binding to the retina was observed in comparison to control phage.

Additional retina homing peptides were obtained and the amino acid sequences were determined for the inserts (Table 6, below). Peptides that appeared more than one time are indicated. In

particular, the RDV tripeptide motif was present in several different sequence contexts, indicating that the nucleic acids encoding the peptides were derived from a number of independent phage.

These results indicate that the selection of the peptides containing the RDV motif represents the selective binding of several independent phage displaying peptides having the RDV sequence and is not an artifact due, for example, to phage amplification. In addition, in some cases, phage that expressed peptides having the same amino acid sequence were encoded by oligonucleotides having different sequences, therefore confirming that homing of a particular phage to retina is due to the specific peptide expressed on the phage.

These results further demonstrate that the *in vivo* panning method is a generally applicable method for screening a library to identify, for example, phage expressing peptides that home to a selected organ or tissue, including organs and tissues containing a component of the RES. Database searches did not reveal any significant homology of the pancreas, lung, skin or retina homing peptides to known ligands for endothelial cell receptors.

EXAMPLE III

IMMUNOHISTOLOGIC ANALYSIS OF LUNG, PANCREAS AND SKIN HOMING PEPTIDES

This example demonstrates the localization of lung, pancreas and skin homing molecules using immunohistologic examination.

Phage displaying homing peptides were detected in lung, pancreas and skin by immunostaining histologic sections obtained 5 min after administration of phage expressing a lung, pancreas or skin homing peptide ("peptide-phage") to a mouse. Following administration of the peptide-phage, mice were handled as described above and various organs, including lung, pancreas and skin, were removed and fixed in Bouin's solution (SIGMA). Histologic sections were prepared and reacted with anti-M13 (phage) antibodies (Pharmacia Biotech; see U.S. Patent No. 5,622,699, *supra*, 1997; Pasqualini and Ruoslahti, *supra*, 1996). Visualization of the bound anti-M13 antibody was performed using a second antibody conjugated to peroxidase (SIGMA) according to the manufacturer's instructions.

Phage displaying the lung homing peptide, GFE-1 (SEQ ID NO: 1), were administered intravenously to mice and, after 5 minutes of circulation, the lung was isolated and processed as described above. Immunohistochemical staining of the alveolar capillaries was observed and no preference for any anatomical portion was detected. However, staining of bronchiolar walls and some larger blood vessels was absent. Mice injected with unselected phage did not exhibit lung staining, and no staining was observed in pancreas and skin after injection of GFE-1 (SEQ ID NO: 1).

Similar experiments were performed in pancreas using phage displaying the pancreas homing peptide, SWCEPGWCR (SEQ ID NO: 4). In these experiments, histological samples of the pancreas as

well as control organs and tissues including lung and skin were prepared and examined by immunostaining as described above. The results revealed staining in the capillaries and larger blood vessels of the exocrine pancreas whereas little if any staining of the endocrine pancreas was detected. Again, unselected phage did not stain pancreas, nor was any staining observed in lung and skin of mice injected with phage displaying SWCEPGWCR (SEQ ID NO: 4). Interestingly, some staining of blood vessels within the uterus was observed for the SWCEPGWCR (SEQ ID NO: 4) peptide. Moreover, after intravenous injection of phage displaying SWCEPGWCR (SEQ ID NO: 4), the phage was recovered from uterus at a 6x higher level in comparison to unselected phage. Thus, SWCEPGWCR (SEQ ID NO: 4) homes to both pancreas and uterus.

Experiments were performed in skin using phage displaying the skin homing peptide CVALCREACGEGC (SEQ ID NO: 3). In these experiments, histological samples from the skin as well as control organs and tissues including lung and pancreas were prepared and examined by immunostaining as described above. The results revealed staining in blood vessels of the hypodermis whereas little if any staining of the dermis was detected. Again, unselected phage did not stain these blood vessels, and no staining was observed in control the lung and pancreas of mice injected with phage displaying CVALCREACGEGC (SEQ ID NO: 3).

All phage, including unselected phage, caused staining of the liver and spleen. This result is consistent with the capture of phage by a component of the RES which was previously described.

These results demonstrate that lung, pancreas and skin homing peptides selectively home to lung, pancreas and skin, particularly to the vasculature. In addition, these results reveal that organs and tissues can exhibit differences of the staining patterns within particular regions, presumably reflecting the differential expression of a target molecule within the organ or tissue. Immunohistochemical analysis provides a convenient assay for identifying the localization and distribution of phage expressing lung, pancreas and skin homing peptides.

EXAMPLE IV

THE RECEPTOR FOR THE GFE-1 LUNG HOMING PEPTIDE IS MEMBRANE DIPEPTIDASE

This example demonstrates that the receptor for "GFE" containing peptides such as GFE-1 (SEQ ID NO: 1) is membrane dipeptidase. This example further demonstrates that GFE-1 (SEQ ID NO: 1) binds and inhibits membrane dipeptidase activity.

A. GFE-1 phage bind selectively to lung primary cells

As described above, CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) phage bind to mouse lung vasculature when injected *in vivo*. A phage binding assay on lung primary cells was performed to determine if the specificity of CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) phage binding to lung tissue *in vivo* could be reconstituted *in vitro*.

Phage binding to primary cells was performed as follows. Briefly, Balb/c mice (Harlan Sprague

Dawley) were anesthetized with 0.017 ml/g of Avertin as described in Gardner et al., Lab. Animal Sci. 45:199-204 (1995), which is incorporated herein by reference. Under deep anesthesia, mice were perfused through the heart with 10 ml Dulbecco's modified Eagle's medium (DMEM; Irvine Scientific; Santa Ana, CA). The lungs, kidneys and brain were then collected, minced, placed in 2 ml of DMEM containing 0.5 % BSA (Intergen; Purchase, NY) and 0.5 µg/ml collagenase V (SIGMA) and incubated at 37 °C for 25 minutes. Following collagenase treatment, the tissue was forced through a 70 µM pore cell strainer (Becton Dickinson; Franklin Lake, NJ). The filtered cells were washed once with 10 ml DMEM supplemented with 10% serum. The phage particles used in the binding assay were amplified and purified, and the phage-displayed inserts were sequenced as described in Smith and Scott, *supra,* 1993. To ensure an equal input of the different phage to be tested, phage were titered several times using K91Kan bacteria (Smith and Scott, *supra,* 1993).

For the binding reaction, 10^9 transducing units (TU) of phage were incubated with 5 X 10^6 cells in 1 ml DMEM supplemented with 10% serum. The binding was performed at 4 °C for 2 hours with gentle agitation. After the binding reaction, the cells were washed four times with 1 ml of DMEM supplemented with 10% serum at room temperature for 5 to 10 minutes each time. The cells were centrifuged, and the cell pellet resuspended in 100 µl of DMEM and transferred to a new tube. The phage bound to the cells were rescued by adding 1 ml of K91Kan bacterial culture (Smith and Scott, *supra,* 1993) followed by incubation at room temperature for 30 minutes. The bacteria were then

diluted in 10 ml of LB culture media supplemented with 0.2 µg/ml tetracycline, and incubated for another 30 minutes at room temperature. Serial dilutions of the bacterial culture were plated on LB plates containing 40 µg/ml tetracycline. Plates were incubated at 37 °C overnight before the colonies were counted (transducing units, TU).

The results of the phage binding assay on primary lung cells *in vitro* showed that primary lung cells bound about 60-fold more CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) phage than insertless fd-tet phage. Binding of CGFECVRQCPERC (SEQ ID NO: 1; GFE-1) phage to kidney cells was also higher than fd-tet binding (t test, $p<0.02$) although this binding was much lower than the GFE-1 (SEQ ID NO: 1) binding on lung cells. In *in vivo* studies, no specific phage homing to kidney was detected when the GFE-1 (SEQ ID NO: 1) phage was injected intravenously. The GFE-1 (SEQ ID NO: 1) phage showed no specific binding to primary brain cells *in vitro*.

GFE-1 (SEQ ID NO: 1) phage binding to lung cells was inhibited by almost 70% in the presence of 150 µM GFE-1 (SEQ ID NO: 1) peptide, whereas the same concentration of a control peptide, GRGESP (SEQ ID NO: 442), had no effect. The non-specific binding of the insertless fd-tet phage was not affected by the presence of GFE-1 (SEQ ID NO: 1) or control peptides. These results demonstrate that the selective *in vivo* binding of the GFE-1 (SEQ ID NO: 1) peptide sequence to lung endothelium can be reconstituted in an *in vitro* assay on total lung primary cells and that whole lung

cell extracts contain sufficient amounts of GFE-1 receptor for isolation.

B. The GFE-1 (SEQ ID NO: 1) peptide binds a 55 kDa surface protein

To detect only the cell surface molecules that bind to GFE-1 (SEQ ID NO: 1), mouse lung endothelial surface proteins were biotinylated *in vivo*, and a total lung extract prepared. The labeled extract was first fractionated on a GFE-1 (SEQ ID NO: 1) peptide affinity column; subsequently, the column was washed, and bound proteins were eluted with a GFE-1 (SEQ ID NO: 1) peptide solution.

In vivo biotinylation of endothelial cell surface proteins was performed as previously described in De La Fuente et al., Am. J. Physiol. 272: L461-L470 (1997), which is incorporated herein by reference, with several modifications. Briefly, Balb/c mice were anesthetized with Avertin and perfused slowly through the heart for 10 to 15 minutes with approximately 15 ml of PBS containing 0.5 mg/ml of sulfo-NHS-LC-biotin (Pierce; Rockford, IL). Well perfused lungs or control tissues such as brain were then collected and incubated on ice for 20 minutes. The tissues were then homogenized for preparation of extracts as described further below.

For preparation of extracts, mouse or rat lungs were first minced and then homogenized with a Brinkman homogenizer (Brinkman; Wesbury, NY) in a minimal volume (2.5 ml/g of tissue) of cold PBS containing 100 mM N-octyl-β-D-glucopyranoside

(Calbiochem; La Jolla, CA) with 1 mM phenylmethylsulfonyl fluoride (PMSF), 20 µg/ml aprotinin and 1 µg/ml leupeptin (PBS/octylglucoside). The homogenized tissue was incubated on ice for 2 hours, and then centrifuged at 12,000 x g for 30 minutes to remove cell debris. The pooled supernatants were cleared of any debris prior to affinity chromatogaphy.

GFE-1 (SEQ ID NO: 1) affinity chromatography was performed according to the general principles established by Pytela et al. for the isolation of integrins by RGD peptide chromatography (Pytela et al., Cell 40:191-198 (1985); Pytela et al., Methods Enzym. 144:475-489 (1987), each of which is incorporated herein by reference). All steps were performed at 4 °C. Briefly, GFE-1 (SEQ ID NO: 1) or control peptides (AnaSpec; San Jose, CA) were coupled to CNBr-activated Sepharose 4B according to the manufacturer's instructions (Pharmacia Biotech; Uppsala, Sweden). The matrix contained approximately 2 mg/ml of peptide. The biotin-labeled extract from 2 mouse lungs was applied to 500 µl of the affinity matrix equilibrated in column buffer (PBS containing 50 mM octylglucoside and 1 mM PMSF). The extract was applied to the column, and the flow-through re-applied over a period of 90 minutes. The column was then washed with 20 volumes of column buffer. Elution with the synthetic GFE-1 (SEQ ID NO: 1) peptide was carried out by slowly washing the column over a period of 1 hour with 2 volumes of column buffer supplemented with 1 mg/ml of GFE-1 peptide (SEQ ID NO: 1) . The remaining proteins bound to the column were eluted with 8 M urea.

Eluates were concentrated 5-fold using a Centricon 10,000 MWCO column (Amicon; Beverly, MA). Aliquots of each elution were then separated by SDS-PAGE using pre-cast polyacrylamide 4-12% gels (Novex; San Diego, CA). For the experiments done with biotin-labeled extracts, the proteins were transferred to a PVDF membrane (Millipore; Bedford, MA), blotted with streptavidin-HRP (Pierce; Rockford, IL) and developed with the ECL chemiluminescence system (NEN; Boston, MA).

As shown in Figure 4 (left panel), a 55 kDa biotinylated protein was selectively eluted by GFE-1 (SEQ ID NO: 1). Prior to elution, the washes from the column showed no detectable biotinylated proteins; subsequent addition of 8 M urea eluted many biotinylated proteins that were retained non-specifically in the column. No proteins in the 55 kDa range were detected after performing the same procedure on a control peptide (GRGESP; SEQ ID NO: 442) column (Figure 4; right panel). As an additional control, an *in vivo* biotinylated brain cell extract was fractionated through a GFE-1 (SEQ ID NO: 1) peptide column under the same conditions; no biotinylated proteins from the brain extract specifically bound to the GFE-1 (SEQ ID NO: 1) peptide column (data not shown).

These results indicate that GFE-1 peptide (SEQ ID NO: 1) specifically binds to a 55 kDa lung vascular surface protein. Under non-reducing conditions, the 55 kDa protein migrated as a 110 kDa band (data not shown). Thus, these results further

indicate that the GFE receptor is a disulfide-linked homodimer.

C. The 55 kDa GFE-1 (SEQ ID NO: 1) receptor is membrane dipeptidase

GFE-1 (SEQ ID NO: 1) phage can selectively target rat lung blood vessels when injected in the circulation. To purify a larger amount of the 55 kDa protein than could be obtained from mouse tissues, a non-biotinylated extract was prepared from 100 frozen rat lungs (Pel-Freez Biologicals; Rogers, AR). The large scale extract was prepared essentially as described above with the addition of a second extraction of the pellet with a minimal volume of PBS/octylglucoside.

The large scale extract was fractionated on a GFE-1 (SEQ ID NO: 1) peptide affinity column as described above using 3 ml of affinity matrix. A 55 kDa protein that was detectable by Coomassie blue staining was eluted from the column by GFE-1 peptide SEQ ID NO: 1 (data not shown). This protein, which co-migrated with the 55 kDa surface protein isolated from mouse lung, was subjected to tryptic digestion and sequenced by mass spectrometry at the Harvard University Microchemistry Facility (Boston, MA) by microcapillary reverse phase HPLC tandem mass spectrometry (μLC/MS/MS) on a Finnigan LCQ quadrupole ion trap mass spectrometer.

Two tryptic peptides derived from the 55 kDa protein, YPDLIAELLR (SEQ ID NO: 444) and TTPVIDGHNDLPWQMLTLFNNQLR (SEQ ID NO: 445), showed

complete identity with rat membrane dipeptidase (EC 3.4.13.19), also known as microsomal dipeptidase, dehydropeptidase-1 or MDP. Several other peptides sequences indicated the presence of rat IgG in the sample. Contamination of the sample with IgG is expected in this molecular weight range, given the abundance of IgG in an extract from unperfused lungs.

To confirm that membrane dipeptidase (MDP) is the GFE-1 (SEQ ID NO: 1) peptide binding protein, the 55 kDa protein was assayed for membrane dipeptidase activity. Samples from the affinity chromatography wash fraction and the GFE-1 (SEQ ID NO: 1) peptide eluate (Figure 4) were incubated in the presence of the specific MDP substrate Gly-D-Phe, and D-Phe detected fluorimetrically exactly as described in Heywood and Hooper, *supra,* 1995 (see, also, Keynan et al., *supra,* 1996). Briefly, the samples were first incubated at 37 °C for 3 hours with the MDP substrate Gly-D-Phe (1 mM; SIGMA). The released D-Phe was then converted to 6,6'-dihydroxy-[1,1'-biphenyl]-3,3'-diacetic acid in the presence of D-amino acid oxydase (Type I; SIGMA) and peroxidase (Type VI; SIGMA; Heywood and Hooper, *supra,* 1995). Fluorescence was measured using an *fmax* fluorescence microplate reader from Molecular Devices (Sunnyvale, CA).

Figure 5 shows a time course of the conversion of D-Phe into a fluorescent compound in samples from the affinity chromatography wash fraction and GFE-1 peptide eluate described above (Figure 4). While the wash fraction showed only a baseline level of fluorescence, the GFE-1 (SEQ ID NO: 1) peptide eluate contained high membrane dipeptidase activity as

illustrated by the time-dependent conversion of D-Phe (see Figure 5). In addition, GFE-1 (SEQ ID NO: 1) peptide eluate isolated from the rat lung extract also showed strong MDP activity (data not shown). MDP activity also was detected in the total lung extract, although the specific activity was about 600-fold higher for the GFE-1 peptide (SEQ ID NO: 1) eluate (200 nmol D-Phe/min/mg) than for the total rat lung extract (0.34 nmol D-Phe/min/mg).

D. GFE-1 (SEQ ID NO: 1) and GFE-2 (SEQ ID NO: 2) phage bind to cells transfected with MDP

The COS-1 cell line, which is known to have low or no detectable level of MDP activity, has been used extensively to study MDP structure and function (Keynan et al., *supra*, 1996; Keynan et al., Biochem. J. 326:47-51 (1997)). COS-1 cells were trasfected with murine MDP and used to assay binding to SEQ ID NOS: 1 and 2 as described below.

For transfection into COS-1 cells, a murine MDP expression vector was prepared as follows. Total mouse lung RNA was isolated using Qiagen RNA purification columns (Qiagen; Santa Clarita, CA) and used as a template for first strand cDNA synthesis with reverse transcriptase and a mixture of random hexamers and poly-dT oligonucleotides (GIBCO/BRL; Grand Island, NY). Mouse MDP cDNA (Pasqualini et al., J. Cell Biol. 130:1189-1196 (1995)) was amplified from the cDNA pool by PCR using the oligonucleotide pair: CCGCTGGTACCGCAGATCCCTGGGGACCTTG (SEQ ID NO: 446), which contains a Kpn I adaptor, and TCTTTCTAGAGCTCAGAGAGCACTGGAGGAG (SEQ ID NO: 447), which

contains an Xba I adaptor, using Taq polymerase from GIBCO/BRL. The amplified 1.3 kb murine MDP cDNA was digested with Kpn I and Xba I, and inserted into the same sites of the pcDNA3 expression vector (Invitrogen; Carlsbad, CA) using DNA restriction enzymes and T4 DNA ligase from New England Biolabs (Beverly, MA). Successful cloning of the murine MDP cDNA was confirmed by DNA sequencing. Transfection of the COS-1 cells was performed with the Superfect Reagent from Qiagen as recommended by the manufacturer.

Phage binding to COS-1 cells transfected with MDP was determined as follows. Briefly, 10^7 COS-1 cells were transfected with 10 µg of either the MDP expression vector or the vector alone. After 48 hours, cells were scraped gently from the dish, washed once, and subjected to the phage binding assay or membrane dipeptidase activity assay described above. For the phage binding assay, 5 x 10^6 cells and 10^{10} transducing units (TU) of phage input were used. For measurement of membrane dipeptidase activity, 10^6 cells were lysed in 100 µl of PBS/octylglycoside without protease inhibitors. A 10 µl aliquot of the extract was used to measure MDP activity.

As shown in Figure 6A, COS-1 cells transfected with murine MDP showed at least 15-fold higher MDP activity than mock transfected cells. Furthermore, GFE-1 (SEQ ID NO: 1) phage bound COS-1 cells transfected with MDP. As shown in Figure 6B, the GFE-1 (SEQ ID NO: 1) phage bound 4-fold more to MDP transfected cells than to mock transfected cells. Negative control phage, the fd-tet phage and a skin-homing phage (CVALCREACGEGC; SEQ ID NO: 3)

displaying a peptide with structural features similar to those of the GFE-1 (SEQ ID NO: 1) peptide, showed no specific binding to cells expressing MDP as compared to mock transfected cells. In addition, Figure 6B shows that GFE-2 (SEQ ID NO: 2) phage also bound MDP transfected cells; the binding was weaker than the GFE-1 (SEQ ID NO: 1) binding in agreement with the *in vivo* lung homing data described above. The binding of both GFE-1 (SEQ ID NO: 1) and GFE-2 (SEQ ID NO: 2) phage to MDP-transfected cells was completely inhibited by GFE-1 peptide (SEQ ID NO: 1; data not shown). These results indicate that the GFE-1 (SEQ ID NO: 1) and GFE-2 (SEQ ID NO: 2) peptides bind the same receptor.

E. GFE-1 (SEQ ID NO: 1) can inhibit MDP activity

The metabolism of the tripeptide glutathione involves cleavage of the tripeptide by γ-glutamyl transpeptidase to form glutamate and cysteinylglycine (Cys-Gly). The dipeptide Cys-Gly is subsequently recognized and cleaved by MDP, which cleaves only dipeptides. The amino acid sequence of glutathione is similar to the N-terminal portion of the GFE-1 peptide CGFECVRQCPERC (SEQ ID NO: 1), with the first two first amino acids of GFE-1 being Cys-Gly.

GFE-1 (SEQ ID NO: 1) was assayed for the ability to inhibit hydrolysis of Gly-D-Phe by MDP. Fluorimetric detection of D-Phe was performed as described above. Figure 7 shows that GFE-1 (SEQ ID NO: 1) inhibited hydrolysis of the Gly-D-Phe substrate (0.5 mM) in a dose-dependent manner. A control cyclic peptide (CARAC; SEQ ID NO: 443) did not inhibit the enzyme.

These results indicate that GFE-1 (SEQ ID NO: 1) can act as a competitive inhibitor of MDP activity.

EXAMPLE V

GFE-1 (SEQ ID NO: 1) INHIBITS LUNG METASTASIS

This example demonstrates that the GFE-1 peptide SEQ ID NO: 1 can inhibit experimental lung metastasis in mice.

Experimental lung metastasis was induced in mice using C8161 human melanoma cells essentially as described in Arap et al., Science 279:377-380 (1998) and Pasqualini et al., Nature Med. 11:1197-1203, each of which is incorporated herein by reference. Briefly, C8161 cells were cultured to 75% confluence and then collected with 2.5 mM EDTA/PBS. The C8161 cancer cells were injected into the tail vein of female nude BALB/c mice (two months old) at a concentration of 10^5 cells per animal. Two sets of five mice were injected with the cells alone; cells with 250 µg control CARAC peptide (SEQ ID NO: 443) or cells with 250 µg GFE-1 peptide (SEQ ID NO: 1). Each injection was in a total volume of 200 µl.

Aliquots of the melanoma cells and peptide mixture were cultured overnight to confirm that the peptides do not affect viability of the tumor cells. Neither the GFE-1 (SEQ ID NO: 1) or CARAC (SEQ ID NO: 443) peptides exhibited toxicity to the melanoma cells (data not shown).

Mice were sacrificed five weeks after injection, and the lungs collected and weighed. As shown in Figure 8, the lung weight of mice administered GFE-1 (SEQ ID NO: 1) peptide was signficantly less than the lung weight seen in mice administered melanoma cells alone ("vehicle") or melanoma cells with control peptide CARAC SEQ ID NO: 443 ("control peptide"). These results indicate that GFE-1 can inhibit lung metastasis of human cancer cells.

A similar lung metastasis experiment was performed using a GFE-1 (SEQ ID NO: 1) glutathione S-transferase fusion protein prepared as described in Rajotte et al., J. Clinical Invest. 102:430-437 (1998), which is incorporated herein by reference. The GFE-1 (SEQ ID NO: 1) glutathione S-transferase fusion protein inhibited the increase in lung weight resulting from injection of C8161 human melanoma cells in a manner similar to the results observed with peptide SEQ ID NO: 1 as shown in Figure 8.

These results indicate that GFE-1 (SEQ ID NO: 1) can inhibit lung metastasis and that MDP serves as a receptor for metastasizing tumor cells on lung vasculature.

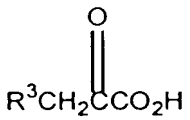
EXAMPLE VI

PREPARATION OF Z-2-ACYLAMINO-3-MONOSUBSTITUTED PROPENOATE MDP-BINDING HOMING MOLECULES

This example demonstrates several methods for preparation of MDP-binding molecules having Structure 1.

A. Method for preparation of an MDP-binding homing molecule having Structure 1

An MDP-binding homing molecule having Structure 1 is made by condensing directly the appropriate 2-keto acid and amide as follows:



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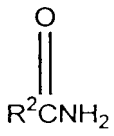
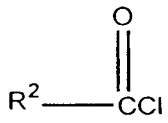


wherein R^2 and R^3 are as defined. The general reaction conditions involve mixing approximately 14: 1 parts of the acid to the amide in an inert solvent such as toluene or methyl isovalerate and heating at reflux with azeotropic removal of water for 3-48 hours, preferably 5-24 hours. The solution when cooled normally yields the product in crystalline form. If desired, the product is isolated using a base extraction process. The product is recrystallized using generally known techniques.

An optional modification of this procedure requires an additional small amount of p-toluenesulfonic
acid as catalyst during the reaction.

B. Method for preparation of an MDP-binding homing molecule having Structure 1

An MDP-binding homing molecule having Structure 1 is prepared using an α-amino acid, t-butyl ester in reaction with an acid chloride as follows:



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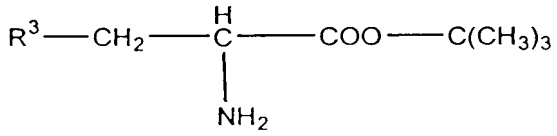
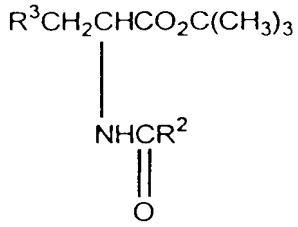
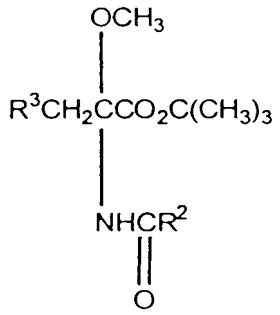
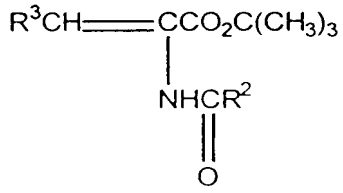


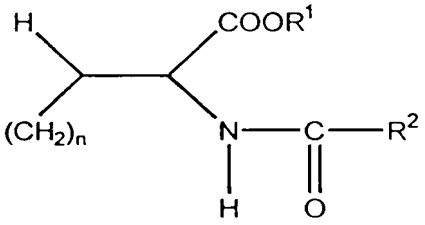
The reaction takes place in the presence of base, such as triethylamine, in a solvent such as methylene chloride. The resulting N-acylated product is then oxidized by treatment with t-butyl hypochlorite followed by addition of sodium methoxide. This yields the 2-methoxy derivative or its elimination product, the α,β-unsaturated ester. Further treatment with anhydrous hydrochloric acid converts either the 2-methoxy derivative or the unsaturated ester (or the mixture of both) to the desired α,β-unsaturated free acid.







Some compounds in which R^3 has a terminal substituent which is an amino, quaternary nitrogen, thiol or carboxyl, derivative can be made most conveniently from an intermediate having a terminal bromine. In this case the intermediate has the structure

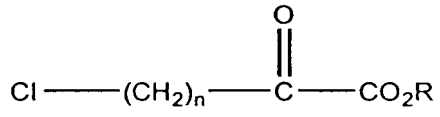


where n is the number of carbons in the desired hydrocarbon chain (e.g., from 3-7).

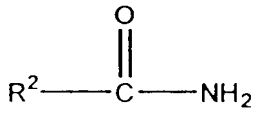
In order to prepare R^3 having a terminal trimethylammonium substituent, the bromo intermediate is reacted with trimethylamine; to yield the amino, the bromo intermediate is reacted with ammonia; the guanidino reaction is with guanidine; to prepare the thio derivatives, including 2-amino-2-carboxyethylthio, the bromo compound is reacted with cysteine HCl, or the appropriate mercaptan. Derivatized amino, such as formamidino, ureido, and acylamide (acetamido) are made from the compounds having an amino group by reacting with o-benzyl formimidate HCl, potassium cyanate and the appropriate acyl anhydride (acetic anhydride) respectively.

C. Method for preparation of an MDP-binding homing molecule having Structure 1

Another route for preparing compounds when R^3 is a terminally substituted thio derivative utilizes a chloroketo ester intermediate as follows:



in reaction with the desired amide,



in toluene at reflux in the presence of a catalytic amount of p-toluenesulfonic acid. The resulting

intermediate is hydrolyzed to the acid; the chloro group is then displaced in reaction with the appropriate mercaptan. This reaction is valuable since it permits use of the chiral amide, thereby preparing a functionalized side chain. Alternatively, the mixture of Z+E isomers prepared after the mercaptan condensation is directly isomerized into the Z form by adding acid to a pH of about 3, and heating to about 90 °C for 30 minutes. Only the Z form remains, and recovery is simple and straight-forward.

D. Preparation of Sodium Z-7-(L-amino-2-carboxyethylthio)-2- (2,2-dimethylcyclopropane carboxamido)-2-heptenoic acid

1. Grignard preparation of ethyl-7-chloro-2-oxoheptanoate

Equimolar amounts (8 moles each) of I-bromo-5-chloropentane and magnesium are reacted in tetrahydrofuran (THF) (960 ml) at 25 °C. The flask is charged with the magnesium in the THF, and the bromochloropentane added over 1 hour, then aged 2 hours. After the reaction is judged complete, the reaction solution is added (cooled -15 °C, to 16 moles of diethyloxalate in 1856 ml THF, while maintaining the temperature at 10 degrees C. 3N HCl is added to quench, keeping the temperature below 25 °C. After stripping solvents, the calculated yield is 48.8% of the ethyl-1-chloro-6-oxoheptenoate.

2. Condensation and Hydrolysis

S-2,2-dimethylcyopropyl carboxamide (1017 g),

2143.6 g of ethyl-7-chloro-2-ketoheptanoate, 9 liters of toluene and 12 g of p-toluene sulfonic acid are charged to a 22 L flask, and heated to reflux with stirring. After 23 hours, liquid chromatography shows the expected product ratio, and 4 L of toluene are removed under slightly reduced pressure. The pot is charged with water, neutralized to pH 7 with 2 N NaOH, and vacuum distilled leaving a final pot volume of about 5 liters. This is hydrolyzed by adding 1760 g of 50% aqueous NaOH (4 liters water) and stirring overnight. The flask is charged with 4 L methylene chloride, and pH adjusted to 8.8 using HCl. Unreacted amide crystallizes out. The organic layers are separated from water, and then evaporated. The gummy residue is dissolved in 8 L water containing 720 g, 50% NaOH, and to this solution is charged 1818 g L-cysteine Hcl, H_20, 2 kg ice, 2484 g 50% NaOH and 1 L water. The pH of this solution, after aging overnight at room temperature, is adjusted to 3.0 with concentrated HCl, and the resulting gummy suspension is heated to 95 °C to afford a clear solution. After 30 minutes, no E isomer is detected by 1c. After work-up and purification, the overall yield is 2060 g, 87% yield. This material is recrystallized from acetonitrile. 1500 g of the recrystallized material is dissolved in 6 L water and 910 ml 3.88 N NaOH, then neutralized to pH 7, and lyophilized to afford 1569 g (98.6%) of the title compound. Analysis: Calcd,: C, 50.52; H, 6.62; N, 7.36; S, 8.43; Na, 6.04. Found: C, 50.71; H, 6.78; N, 7.49; S, 8.52; Na, 5.92

All journal article, reference, and patent citations provided above, in parentheses or otherwise,

whether previously stated or not, are incorporated herein by reference.

Although the invention has been described with reference to the examples provided above, it should be understood that various modifications can be made without departing from the spirit of the invention. Accordingly, the invention is limited only by the claims.

TABLE 2

PEPTIDES FROM PHAGE RECOVERED FROM LUNG

CIKGNVNC (32)	CRHESSSC (33)
CLYIDRRC (34)	CYSLGADC (35)
CSKLMMTC (349)	CGFELETC* (2)
CNSDVDLC (36)	CVGNLSMC* (37)
CEKKLLYC (38)	CKGQRDFC* (39)
CTFRNASC (40)	CNMGLTRC* (41)
CHEGYLTC* (42)	CGTFGARC (43)
CIGEVEVC* (16)	CRISAHPC (44)
CLRPYLNC* (45)	CSYPKILC (46)
CMELSKQC* (47)	CSEPSGTC (48)
CGNETLRC (49)	CTLSNRFC (50)
CMGSEYWC (51)	CLFSDENC* (52)
CAHQHIQC (53)	CKGQGDWC (54)
CAQNMLCC (55)	CWRGDRKIC* (56)
CLAKENVVC* (13)	CIFREANVC (57)
CRTHGYQGC (58)	CERVVGSSC (59)
CKTNHMESC (60)	CYEEKSQSC (61)
CKDSAMTIC (62)	CTRSTNTGC (63)
CMSWDAVSC* (64)	CKWSRLHSC* (65)
CMSPQRSDC (66)	CLHSPRSKC (67)
CPQDIRRNC (68)	CLYTKEQRC (69)
CQTRNFAQC (70)	CTGHLSTDC (71)
CQDLNIMQC (72)	TRRTNNPLT (73)
CGYIDPNRISQC (74)	CTVNEAYKTRMC* (75)
CRLRSYGTLSLC* (76)	CAGTCATGCNGVC (77)
CADYDLALGLMC (78)	CPKARPAPQYKC (79)
CSSHQGGFQHGC (80)	CQETRTEGRKKC (81)
CRPWHNQAHTEC* (82)	CSFGTHDTEPHC (83)

TABLE 2 (cont.)

	CSEAASRMIGVC*	(84)	CWEEHPSIKWWC*	(85)
	CWDADQIFGIKC	(86)	CVDSQSMKGLVC	(87)
	CRLQTMGQGQSC	(88)	CRPAQRDAGTSC	(89)
5	CGGRDRGTYGPC	(90)	CGEVASNERIQC	(91)
	CNSKSSAELEKC	(92)	CVLNFKNQARDC	(93)
	CRGKPLANFEDC	(94)	CEGHSMRGYGLC	(95)
	CRDRGDRMKSLC	(96)	CDNTCTYGVDDC	(97)
	CSAHSQEMNVNC	(98)	CGAACGVGCRGRC	(99)
10	CGFECVRQCPERC*	(1)	CLVGCRLSCGGEC	(100)
	CRSGCVEGCGGRC	(101)	CIARCGGACGRHC	(102)
	CGGECGWECEVSC	(103)	CGVGCPGLCGGAC*	(104)
	CKWLCLLLCAVAC	(105)	CSEGCGPVCWPEC	(106)
	CGAACGVGCGGRC	(107)	CSGSCRRGCGIDC	(108)
15	CGASCALGCRAYC	(109)	CDTSCENNCQGPC	(110)
	CSRQCRGACGQPC	(111)	CYWWCDGVCALQC	(112)
	CAGGCAVRCGGTC	(113)	CGGACGGVCTGGC*	(114)
	CGRPCVGECRMGC	(115)	CLVGCEVGCSPAC	(116)
	CPRTCGAACASPC	(117)	CRGDCGIGCRRLC	(118)
20	CCFTNFDCYLGC	(435)		

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.

TABLE 3

PEPTIDES FROM PHAGE RECOVERED FROM PANCREAS

EICQLGSCT	(119)	WRCEGFNCQ	(120)
RKCLRPDCG	(121)	SWCEPGWCR*	(4)
LACFVTGCL	(122)	GLCNGATCM*	(123)
DMCWLIGCG	(124)	SGCRTMVCV	(125)
QRCPRSFCL	(126)	LSCAPVICG	(127)
RECTNEICY	(128)	NECLMISCR	(129)
SCVFCDWLS	(130)	WACEELSCF	(131)
QNCPVTRCV	(132)	CATLTNDEC	(133)
CDNREMSC	(134)	CFMDHSNC	(135)
CGEYGREC	(136)	CHMKRDRTC	(137)
CKKRLLNVC	(138)	CLDYHPKC	(139)
CMTGRVTC	(140)	CNKIVRRC	(141)
CPDLLVAC	(142)	CSDTQSIGC	(143)
CSKAYDLAC	(144)	CSKKGPSYC	(145)
CTLKHTAMC	(146)	CTQHIANC	(147)
CTTEIDYC	(148)	CVGRSGELC	(149)

Parentheses contain SEQ ID NO:.

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TABLE 4

PEPTIDES FROM PHAGE RECOVERED FROM GUT

YAGFFLV* (150)	RSGARSS (151)
CVESTVA (152)	SRRQPLS* (153)
SKVWLLL (154)	QVRRVPE (155)
YSGKWGW* (156)	MVQSVG (157)
LRAVGRA (158)	MSPQLAT* (159)
GAVLPGE (160)	WIEEAER* (161)
LVSEQLR (162)	RGDRPPY (163)
VRRGSPQ (164)	RVRGPER (165)
GISAVLS* (166)	GGRGSWE (167)
GVSASDW (168)	FRVRGSP (169)
SRLSGGT (170)	WELVARS (171)
MRRDEQR (172)	GCRCWA (173)
LSPPYMW (7)	LCTAMTE (18)

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TABLE 5

PEPTIDES FROM PHAGE RECOVERED FROM SKIN

CYADCEGTCGMVC (174)	CWNICPGGCRALC* (175)
GPGCEEECQPAC (176)	CKGTCVLGCSEEC* (177)
CSTLCGLRCMGTC (178)	CMPRCGVNCKWAC (179)
CVGACDLKCTGGC (180)	CVALCREACGEGC* (3)
CSSGCSKNCLEMC* (181)	CGRPCRGGCAASC (182)
CQGGCGVSCPIFC (183)	CAVRCDGSCVPEC* (184)
CGFGCSGSCQMQC (185)	CRVVCADGCRFIC (186)
CTMGCTAGCAFAC (187)	CEGKCGLTCECTC (188)
CNQGCSGSCDVMC (189)	CASGCSESCYVGC (190)
CGGGCQWGCAGEC* (191)	CSVRCKSVCIGLC (192)
CPSNCVALCTSGC (193)	CVEGCSSGCGPGC (194)
CRVVCADGCRLIC (195)	CSTLCGLRCMGTC (196)
CFTFCEYHCQLTC (197)	CVDVCCDGCPVCC (437)
RVPLSGDVEH (438)	LRVMSFTSGQ (439)
RFSVGSLFGS (440)	CGATCEMQCPSGC (441)

Parentheses contain SEQ ID NO:.
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TABLE 6

PEPTIDES FROM PHAGE RECOVERED FROM RETINA

CRRIWYAVC (198)	CSAYTTSPC (199)
CSCFRDVCC* (5)	CTDKSWPC (200)
CTDNRVGS (201)	CTIADFPC (202)
CTSDISWWDYKC (203)	CTVDNELC (204)
CVGDCIGSCWMFC (205)	CVKFTYDC[2] (206)
CVSGHLNC (207)	CYGESQQMC (208)
CYTGETWTC (209)	CAVSIPRC (210)
CDCRGDCFC (211)	CDSLCGGACAARC (212)
CERSQSKGVHHC (213)	CFKSTLLC (214)
CFWHNRAC (215)	CGDVCPSECPGWC (216)
CGEFKVGC* (14)	CGLDCLGDCSGAC (217)
CGPGYQAQCSLRC (218)	CGSHCGQLCKSLC (219)
CHMGCVSPCAYVC (220)	CILSYDNPC (221)
CISRPYFC (222)	CKERLEYTRGVC (223)
CKERPSNGLSAC (224)	CKPFRTEC (225)
CKSGCGVACRHMC (226)	CLKPGGQEC (227)
CMDSQSSC* (228)	CMNILSGC (229)
CNIPVTTPIFGC (230)	CNQRTNRESGNC* (231)
CNRKNSNEQRAC (232)	CNRMEMPC (233)
CQIRPIDKC (234)	CAIDIGGAC (235)
CGRFDTAPQRGC (236)	CKRANRLSC (237)
CLLNYTYC* (238)	CLNGLVSMC (239)
CMSLGNNC (240)	CNRNRMTPC (241)
CQASASDHC* (242)	CQLINSSPC (243)
CQRVNSVENASC (244)	CRKEHYPC (245)
CRRHMERC (246)	CSGRPFKYC (247)
CTHLVTLC (248)	CTSSPAYNC (249)
CVTSNLRVC* (250)	CWDSGSHIC (251)
CERSHGRLC[1] (252)	CGNLLTRRC (253)
CINCLSQC (254)	CLRHDFYVC (255)

TABLE 6 (cont.)

CNSRSENC	(256)	CRYKGPSC	(257)
CSHHDTNC	(258)	CSRWYTTC	(259)
CYAGSPLC	(260)	CQTTSWNC*	(261)
CQWSMNVC	(262)	CRARIRAEDISC*	(263)
CRDVVSVIC	(6)	CRREYSAC	(264)

Blast-Search:

[1]rat retinal guanylcyclase precursor EC4.6.1.2

[2]rat glutamate receptor subunit epsilon 1 precursor

No stainings for any motif tested, only evidence for preferential homing are the RDV-containig phages in comparison to an ampicillin-phage.

Parentheses contain SEQ ID NO:.

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TABLE 7

PEPTIDES FROM PHAGE RECOVERED FROM PROSTATE

EVQSAKW (265)	KRVYVLG (266)
GRLSVQV (267)	WKPASLS (268)
FAVRVVG (269)	LVRPLEG (270)
GFYRMLG (271)	EGRPMVY (272)
GSRSLGA (273)	RVWQGDV (274)
GDELLA (275)	FVWLVGS (276)
GSEPMFR (277)	VSFLEYR (22)
WHQPL (278)	SMSIARL* (21)
RGRWLAL* (279)	QVEEFPC (280)
LWLSGNW (281)	GPMLSVM (282)
WTFLERL (283)	VLPGGQW (284)
REVKES (285)	RTPAAVM (286)
GEWLGEC (287)	PNPLMPL (288)
SLWYLGA (289)	YVGGWEL (290)

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.

TABLE 8

PEPTIDES FROM PHAGE RECOVERED FROM OVARY

EVRSRLS*	(10)	RVGLVAR*	(11)
AVKDYFR	(291)	GVRTSIW	(292)
RPVGMRK	(293)	RVRLVNL	(294)
FFAAVRS	(295)	KLVNSSW	(296)
LCERVWR	(297)	FGSQAFV	(298)
WLERPEY	(299)	GGDVMWR	(300)
VRARLMS	(301)	TLRESGP	(302)

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.

TABLE 9

PEPTIDES FROM PHAGE RECOVERED FROM LYMPH NODE

WGCKLRFCS (303	MECIKYSCL (304)
GICATVKCS (305)	PRCQLWACT (306)
TTCMSQLCL (307)	SHCPMASLC (308)
GCVRRLLCN (309)	TSCRLFSCA (310)
KYCTPVECL (311)	RGCNGSRCS (312)
MCPQRNCL (313)	PECEGVSCI (314)
AGCSVTVCG* (315)	IPCYWESCR (316)
GSCSMFPCS* (317)	QDCVKRPCV (318)
SECAYRACS* (319)	WSCARPLCG* (320)
SLCGSDGCR (321)	RLCPSSPCT (322)
MRCGFSGCT (323)	RYCYPDGCL (324)
STCGNWTCR (325)	LPCTGASCP (326)
CSCTGQLCR (327)	LECRRWRCD (328)
GLCQIDECR* (329)	TACKVAACH (330)
DRCLDIWCL* (331)	XXXQGSPCL (332)
PLCMATRCA* (333)	RDCSHRSCE* (334)
NPCLRAACI* (335)	PTCAYGWCA* (336)
LECVANLCT* (337)	RKCGEEVCT* (338)
EPCTWNACL* (339)	LVCPGTACV (340)
LYCLDASCL (341)	ERCPMAKCY (342)
LVCQGSPCL (343)	QQCQDPYCL* (344)
DXCXDIWCL (345)	QPCRSMVCA (346)
KTCVGVRV (347)	WSCHEFMCR (348)
LTCWDWSCR (350)	SLCRLSTCS (351)
KTCAGSSCI (352)	VICTGRQCG (353)
NPCFGLLV (354)	SLCTAFNCH (355)
RTCTPSRCM (356)	QSCLWRICI (357)
QYCWSKGCR (358)	LGCFPSWCG (359)

TABLE 9 (cont.)

	VTCSSEWCL	(360)	RLCSWGGCA	(361)
	STCISVHCS	(362)	EVCLVLSCQ	(363)
	IACDGYLCG	(364)	RDCVKNLCR	(365)
5	XGCYQKRCT	(366)	LGCFXSWCG	(367)
	IRCWGGRCS	(368)	IPCSLLGCA	(369)
	AGCVQSQCY	(370)	PRCWERVCS	(371)
	KACFGADCX	(372)	TLCPLVACE	(373)
	SACWLSNCA	(374)	SECYTGSCP	(375)
10	GLCQEHRCW	(376)	VECGFSAVF	(377)
	EDCREWGCR	(378)	HWCRLLACR	(379)

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.

15 X = Not known.

TABLE 10

PEPTIDES FROM PHAGE RECOVERED FROM ADRENAL GLAND

HKGQVYS	(380)	FSDVHFW* (381)
RGIFVSS	(382)	PKVKLSE (383)
LRFWQES	(384)	IWTVVGQ (385)
DKVGLSV	(386)	SETWRQF (387)
LDGMIVK	(388)	RYPLAGG (389)
FTDGEDK	(390)	RSTEHMS (391)
SGRRHEL	(392)	LMLPRAD* (27)
SSSRVRS	(393)	YHRSVGR (394)
PLLRPPH	(395)	SDKLGFV* (396)
LPRYLLS	(28)	AGSRTNR (397)
ITQLHKT	(398)	ARCLVYR (399)
GYVAVMT*	(400)	GLQVKWV (401)
IFTPGWL	(402)	KQTSRFL (403)
R(Y/F)LLAGG (404)		

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.

TABLE 11

PEPTIDES FROM PHAGE RECOVERED FROM LIVER

ARRGWTL	(405)	SRRFVGG*	(406)
QLTGGCL	(407)	ALERRSL	(408)
KAYFRWR	(409)	RWLAWTV	(410)
VGSFIYS*	(411)	LSLLGIA	(412)
LSTVLWF	(413)	SLAMRDS	(414)
GRSSLAC	(415)	SELLGDA	(416)
CGGAGAR	(417)	WRQNMPL*	(418)
DFLRCRV	(419)	QAGLRCH	(420)
RALYDAL	(421)	WVSVLGF	(422)
GMAVSSW	(423)	SWFFLVA	(424)
WQSVVRV	(425)	VKSVCRT*	(12)
CGNGHSC	(426)	AEMEGRD	(427)
SLRPDNG	(428)	PAMGLIR	(429)

Parentheses contain SEQ ID NO:.

* indicates sequences isolated more than once.